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NOTE—In this Index the names of authors of papers are printed in SMALL CAPITALS and the titles of papers in *italics*. Abstract of Minutes appears in Appendix.

"OPERATING EXPERIENCES WITH STEAM REGENERATORS"

A DISCUSSION

TEST OF STEAM REGENERATORS AND LOW PRESSURE TURBINES

By Frank E. Leahy*

In order to verify the theory of steam accumulative and regenerative processes advanced by Mr. F. G. Gasche, M. E., in his able article on that theme, we wish to offer the results of a series of recent tests made to provide a practical demonstration of this theory on the conservation of steam energy, insofar as it may be applied to the regenerative system at this plant in McKeesport; and as a knowledge of the steam consumption of the turbine was essential to these tests, the results of the turbine tests are also included.

Regenerator System: These investigations were made on the regenerative system which is located between the blooming mill and slabbing mill in front of the low pressure turbine station. It consists of three American Steam Regenerators connected in parallel and operating as a unit. Each regenerator, a side view of which is shown in Fig. 1, consists of two steel tanks, one above the other, the lower being designated as the expansion chamber, and the upper as the regenerative chamber. The lower or expansion chamber is 7 ft. in diameter and 30 ft. long. It is equipped with a float controlled overflow trap to convey off accumulations of water, also in the top of this tank is located the steam and water mixing chamber known as the "spray box." This box is rectangular in shape, 17½ in. wide by 13½ in. high by 16 ft. long and the top is perforated with

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$\frac{3}{16}$ inch holes about $\frac{9}{16}$ inch pitch. On the front of this spray box is a vane connected through levers to a pilot valve, located outside and on top of the tank so that any movement of the vane changes the position of the valve. The pilot valve admits live steam to either side of a steam cylinder which operates the water valve, allowing the water from the upper tank to pass through the holes in the top of the spray box in the lower tank,

Fig. 1. Side View of Regenerator.

breaking it into a spray. The back of the spray box is connected to the ejection pipe, which passes through the bottom and ends near the top of the upper tank.

The upper or regenerative chamber is 8 ft. 6 in. in diameter and 43 ft. long.

It is equipped with gauge glasses and gauge cocks to indicate the height of water; it also has a 16 in. low pressure relief valve opening to the atmosphere, located about the center

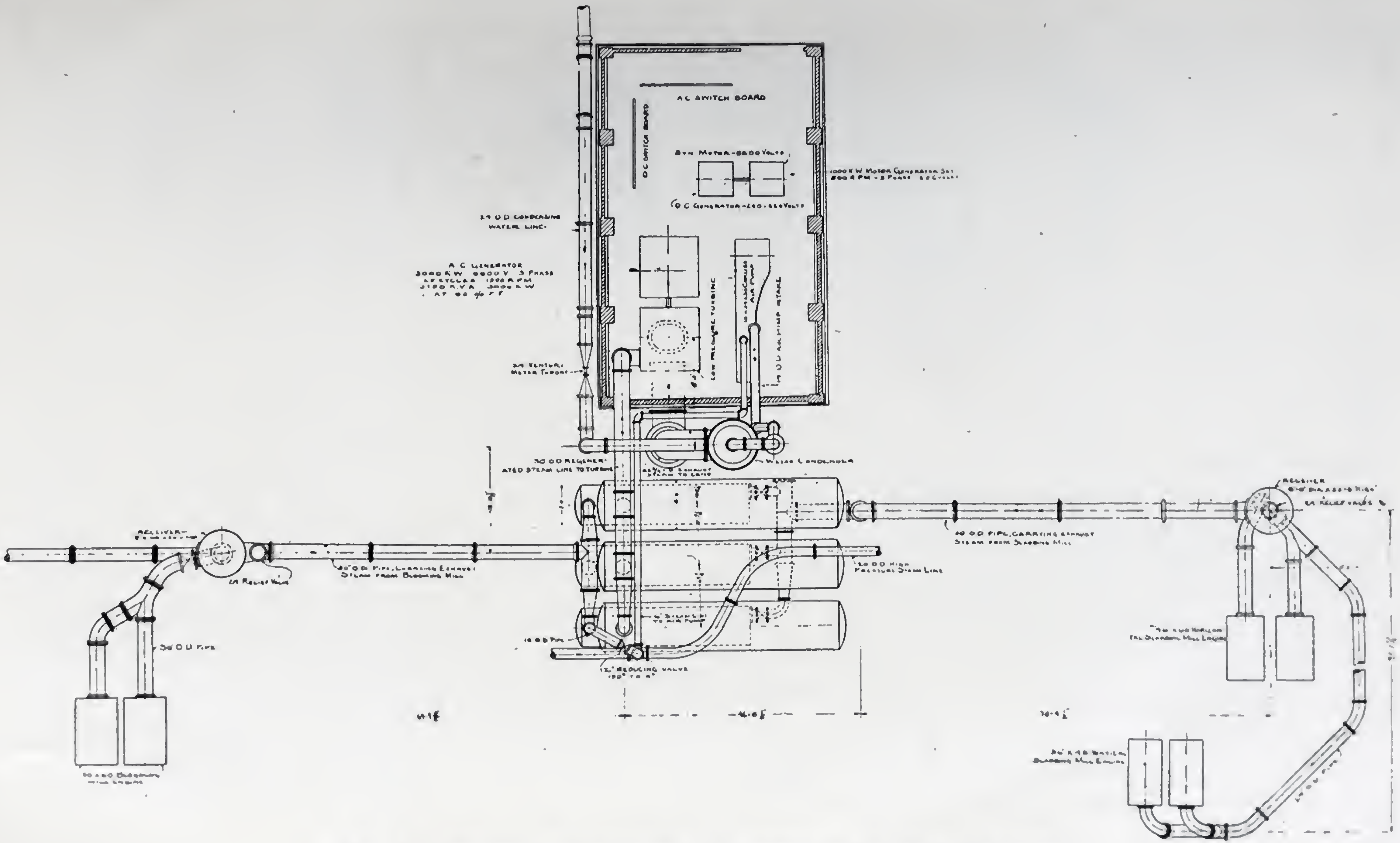


Fig. 2. General Arrangement of Regenerators and Engines.

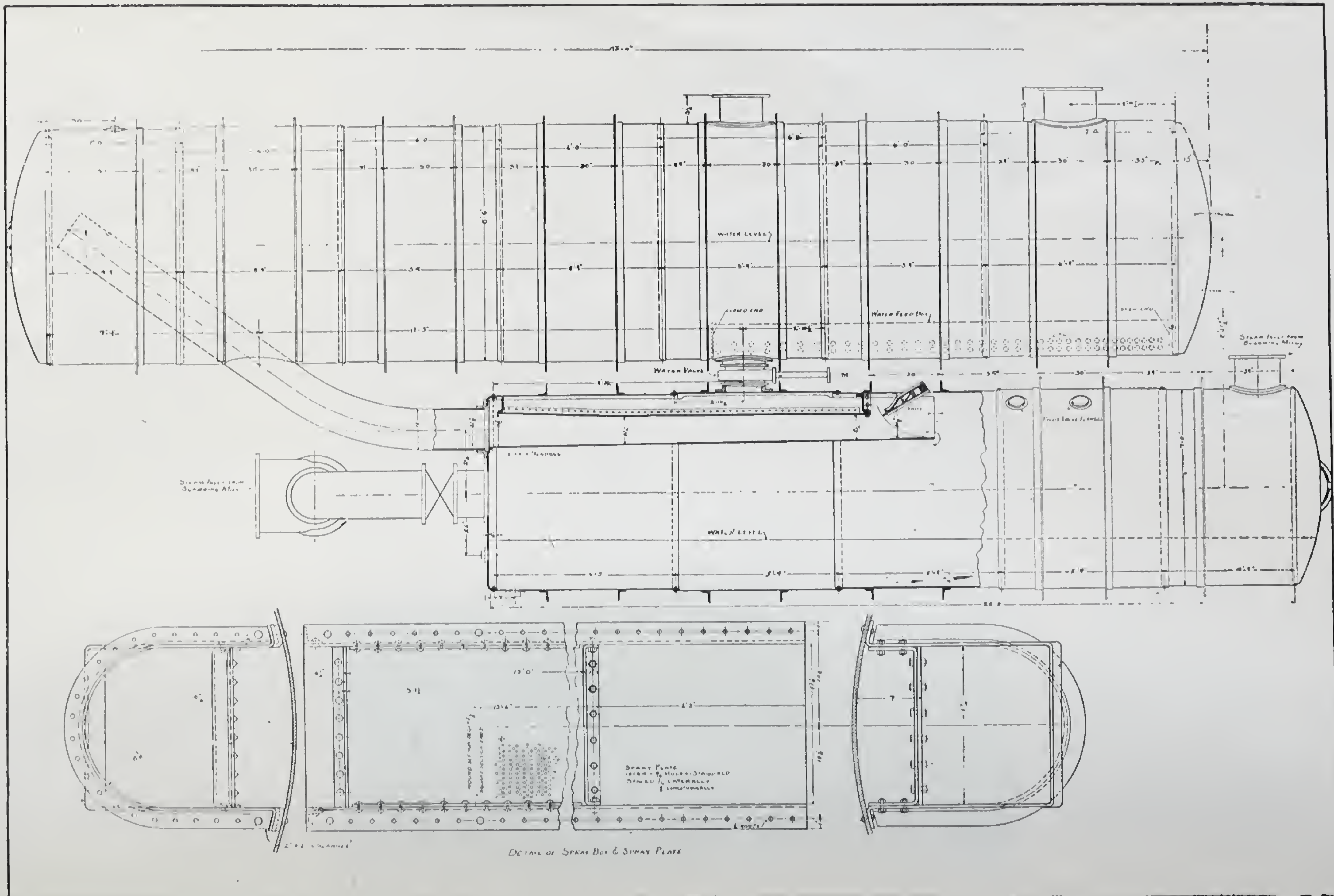


Fig. 3. Detail of Regenerator Tanks, Spray Box and Spray Plate.

of the top of the tank. There is also an over-flow pipe emptying into the lower tank to prevent the water from rising above the desired level. About the center and bottom of this tank is located a 16 in. gate valve, which regulates the flow of water from the upper tank into the spray box in the lower tank as previously described.

The three lower tanks are connected at each end to manifold pipes which distribute the steam to the three regenerators; at the east end steam is received from the slabbing mill engines; and at the west end steam is received from the blooming mill engine. The three upper tanks are connected to a common steam main leading to the turbine. The general arrangement of regenerators and engines is shown on Fig. 2, and the details of the regenerator tanks, spray box, spray plate and water control on Figs. 3 and 4.

Method of Operation of Regenerators: The operation of the regenerative system is as follows: The exhaust steam enters the lower tank and in passing into the spray box strikes a vane, turning it through a certain angle depending upon the quantity of steam flowing. This movement is transmitted to the regulating water valve which admits the water to the spray box; the greater the quantity of steam flowing the greater the angle through which the vane turns and thus admitting more water through the valve. The steam and water meet in the spray box, and the mixture passes through the ejection pipe into the upper tank, the water absorbing heat from the steam on the way. In this manner heat is stored in the upper tank and becomes available for use when required. If at any time the pressure in the top tank drops to 16 lb. absolute, due to a decrease in the supply of exhaust steam, the live steam reducing valve is automatically opened and admits steam to the lower tank, and closes as soon as the pressure in the top tank increases to 18 lb. absolute. If at any time there is such a surplus of exhaust steam that the pressure in the top tank exceeds 19 lb. absolute, the relief valves open, discharging the excess steam to the atmosphere.

Regenerator Tests: This type of regenerator is described in Mr. Gasche's paper as a "Forced Circulation Regenerator"

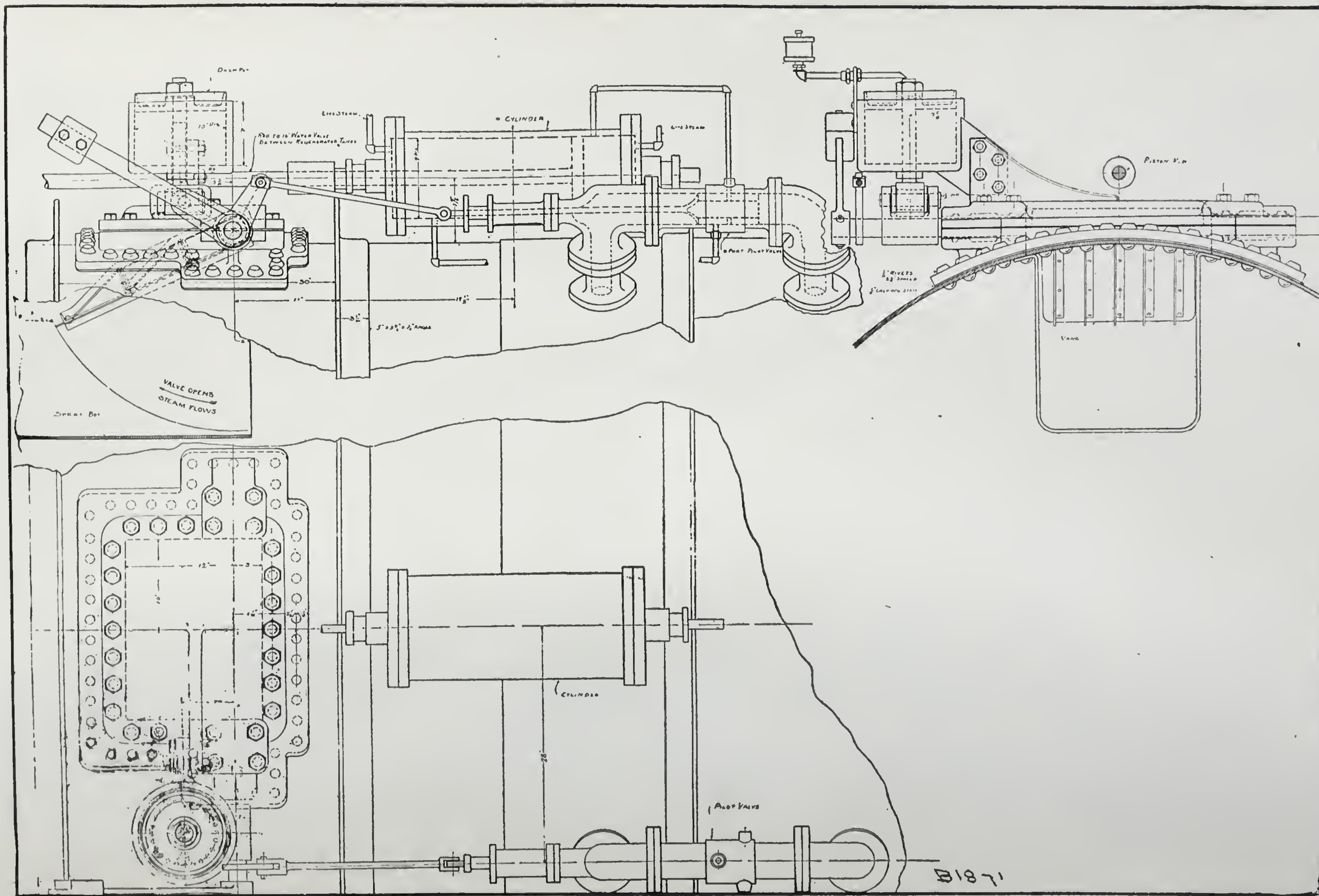


Fig. 4. Arrangement of Water Control on Lower Tank.

in which the circulation is produced by spraying in the steam supply pipe. The theory advanced in this paper states that the spray and the steam are assumed to arrive in the regenerative tank at the same temperature, the water in the said tank having no convective movements of importance during the absorption period; the surface of the water, due to the accumulations from the spray, consequently rises to the temperature of the steam, after which there is no heat transfer by surface contact to the water. This surface is relatively small, and the preceding assumption will simplify the case. The energy and the equivalent heat expenditure to raise the water would be important to the extent of the amount of water in circulation. From the above theory was established the relation between the variables entering into the problems and from these formulae were derived the curves for the absorption and regenerative characteristics, the calculations for which are shown in the appendix.

Owing to the variation in the quantity and duration of the flow of exhaust steam from the engines, it was decided in the tests to use live steam throttled through a reducing valve, in order to better control the conditions of operation. To simplify the tests of the regenerative system, preliminary observations on the simultaneous operation of the three regenerators were taken by recording thermometers and it was discovered, as shown in Fig. 5 and Fig. 6, that the temperature of the water in the three regenerators, taken at the same place, over a period of 24 hours, varied not more than two degrees, indicating that the three regenerators operated as a unit. From this information it was decided to confine the investigation to one regenerator as illustrative of all.

The observations during the tests were taken as follows: The average temperature of the water in the regenerator was determined by thermometers placed in the tank, one three feet from the west end and two feet above the bottom; one at the middle, four feet above bottom; one three feet from the east end, two feet above the bottom, and a recording thermometer in the bottom, midway between both ends. A pressure—time curve is shown in Fig. 7.

The steam temperature was determined by a thermometer

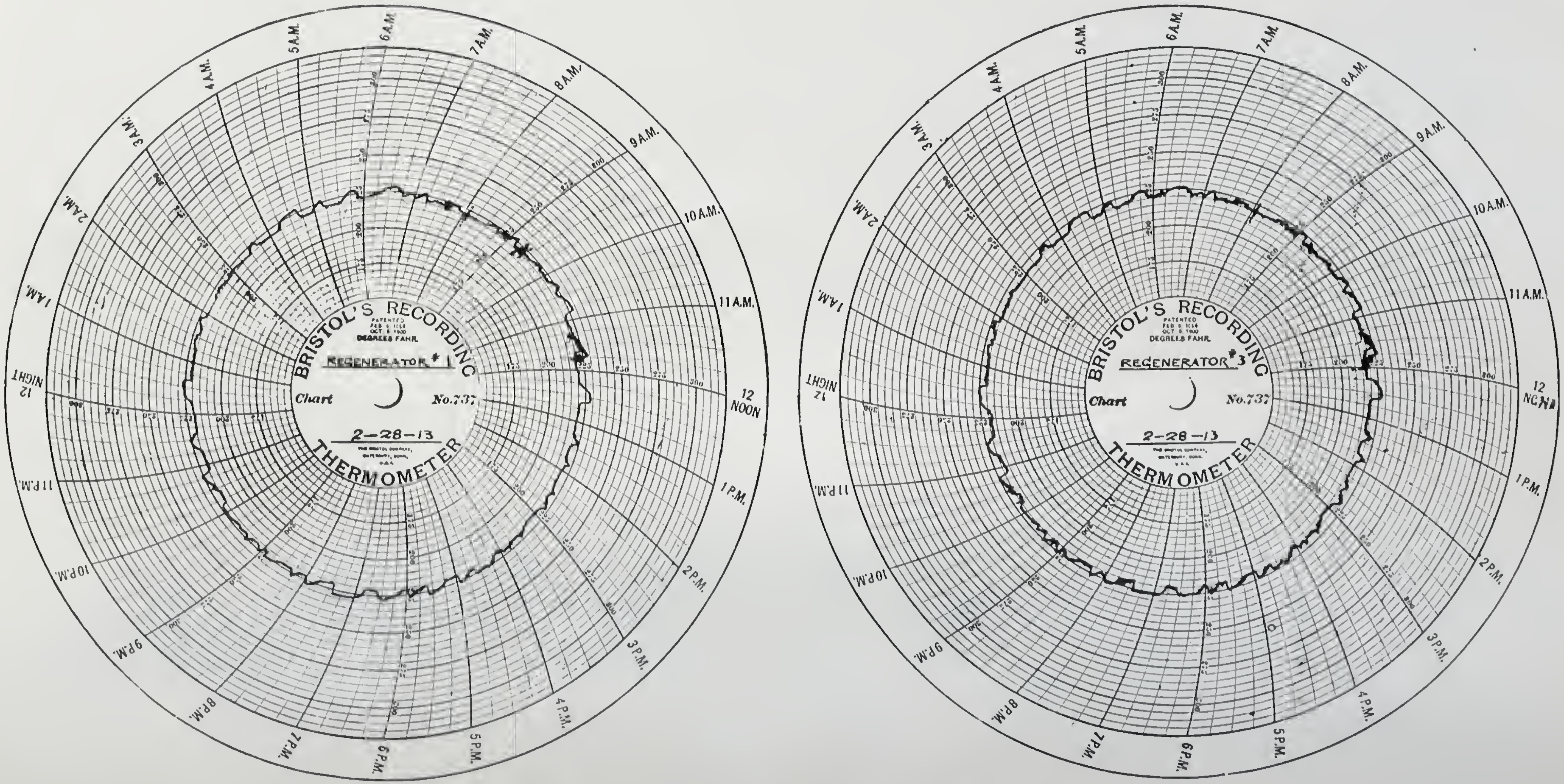


Fig. 5. Temperature—Time Curve.

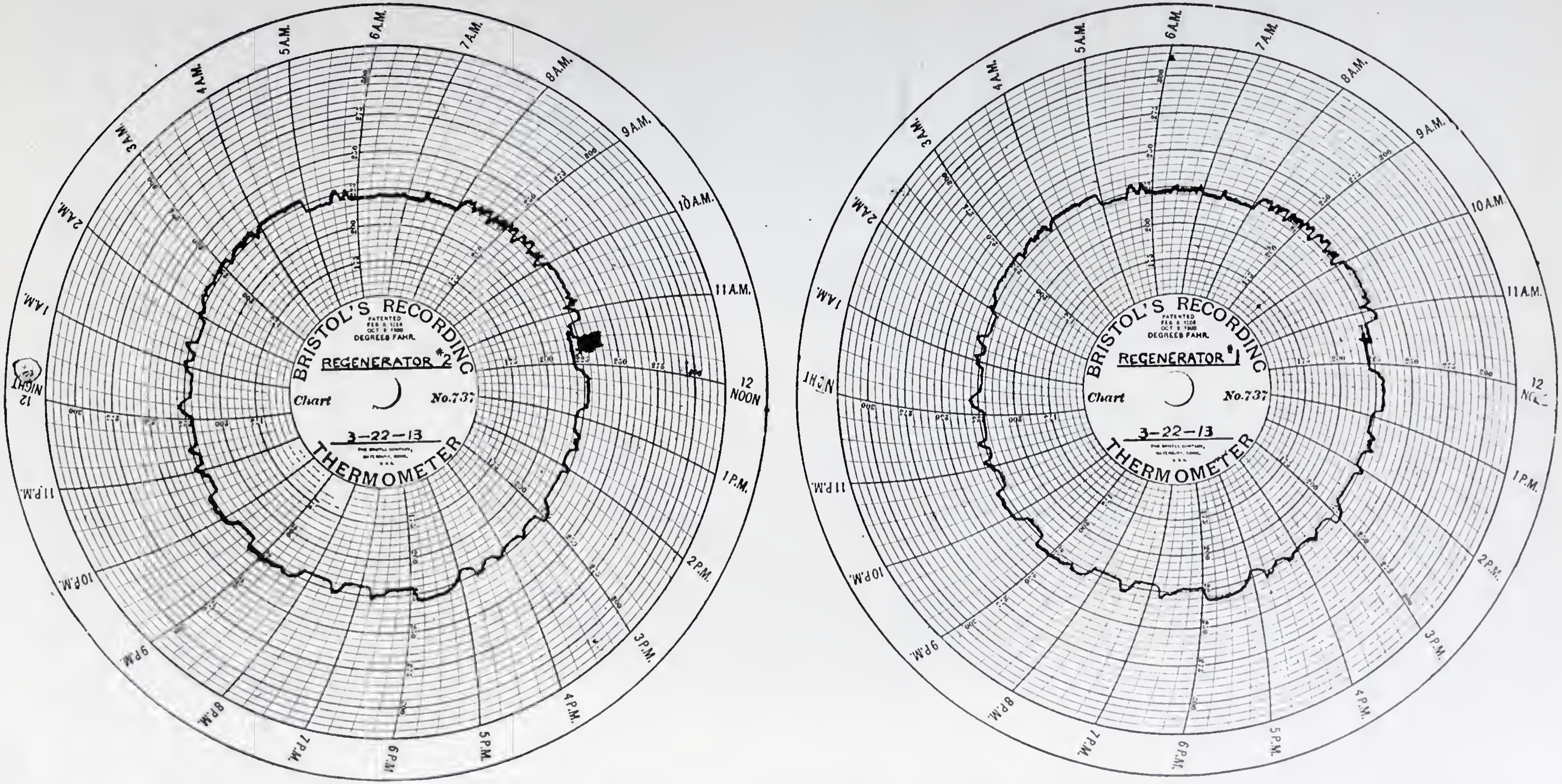


Fig. 6. Temperature—Time Curves.

placed in the top of the regenerative tank. Mercury columns were attached to note the pressure in the top and bottom tanks. Graduated water gauge glasses were placed on both ends of the regenerative tank to indicate the height of water.

An observer was stationed at each thermometer, steam gauge and mercury column and the relief valves were set to blow off at the required pressure; the water in the regenerative tank having been heated to the desired temperature, the live steam valve was quickly opened, the steam passing through the

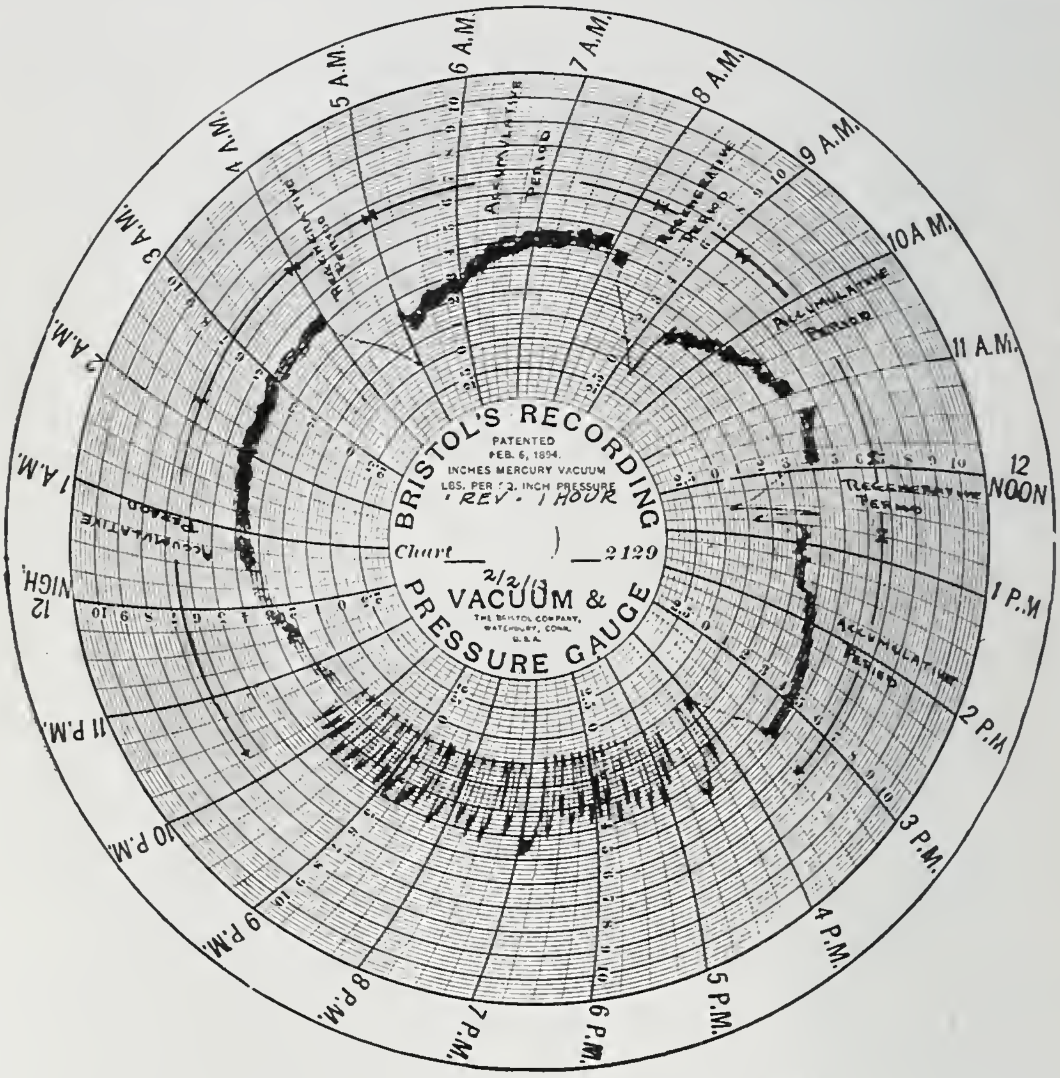


Fig. 7. Pressure—Time Curve.

regenerators and out through the relief valves, the line to the turbine being closed. Simultaneous readings of all thermometers, gauges and mercury columns were taken every ten seconds. A number of absorption tests were run in this manner, having a duration of from three to four minutes.

The regenerative period for these absorption periods was figured as shown in the appendix. It was checked as follows: When the regenerators were charged to the desired pressure

with the turbine running, the live steam reducing valve was immediately closed and steam was supplied from the regcnerators alone to the turbine. The rate at which the heat was abstracted from the regenerator was regulated by the load on the turbine, the steam consumption of which had been previously determined. Readings of all thermometers, gauges, etc., during this period, were taken every ten seconds.

RESULTS OF REGENERATOR TESTS

Test No. 1

Accumulative Period: The length of time that steam was supplied to the regenerators was four minutes. The initial temperature of the water was 205 deg. Fahr., and the final temperature was 216 deg., the temperature of the steam being 229.3 deg. The amount of water circulated per minute was 14 180 lb., and the quantity of heat stored was 1 045 800 B. t. u.

Regenerative Period: The time required to abstract this heat, supplying steam at the rate of 567 lb. of steam per minute, was 89.2 seconds.

Test No. 2

Accumulative Period: Steam was supplied to the regenerator for four minutes. The initial temperature of the water was 206.5 deg. Fahr., and the final temperature was 216.2 deg., the temperature of the steam being 231.2 deg. The amount of water in circulation per minute was 11 028 lb., and the quantity of heat that was stored was 871 257 B. t. u.

Regenerative Period: The time required to abstract this heat, at the rate of 567 lb. of steam per minute, was 79.15 seconds.

Test No. 3

Accumulative Period: Steam was supplied to the regenerator for three minutes. The initial temperature of the water was 206.3 deg. Fahr., and the final temperature was 219.3 deg., the temperature of the steam being 235.5 deg. The amount of water in circulation per minute was 17 371 lb. and the quantity of heat absorbed was 1,164 132 B. t. u.

Regenerative Period: The time required to abstract this heat at the rate of 567 lb. of steam per minute was 103.88 seconds.

Test No. 4

Accumulative Period: Steam was supplied to the regenerator for three minutes. The initial temperature of the water was 195.2 deg. Fahr., and the final temperature was 214.2 deg., the temperature of the steam being 232.1 deg. The amount of

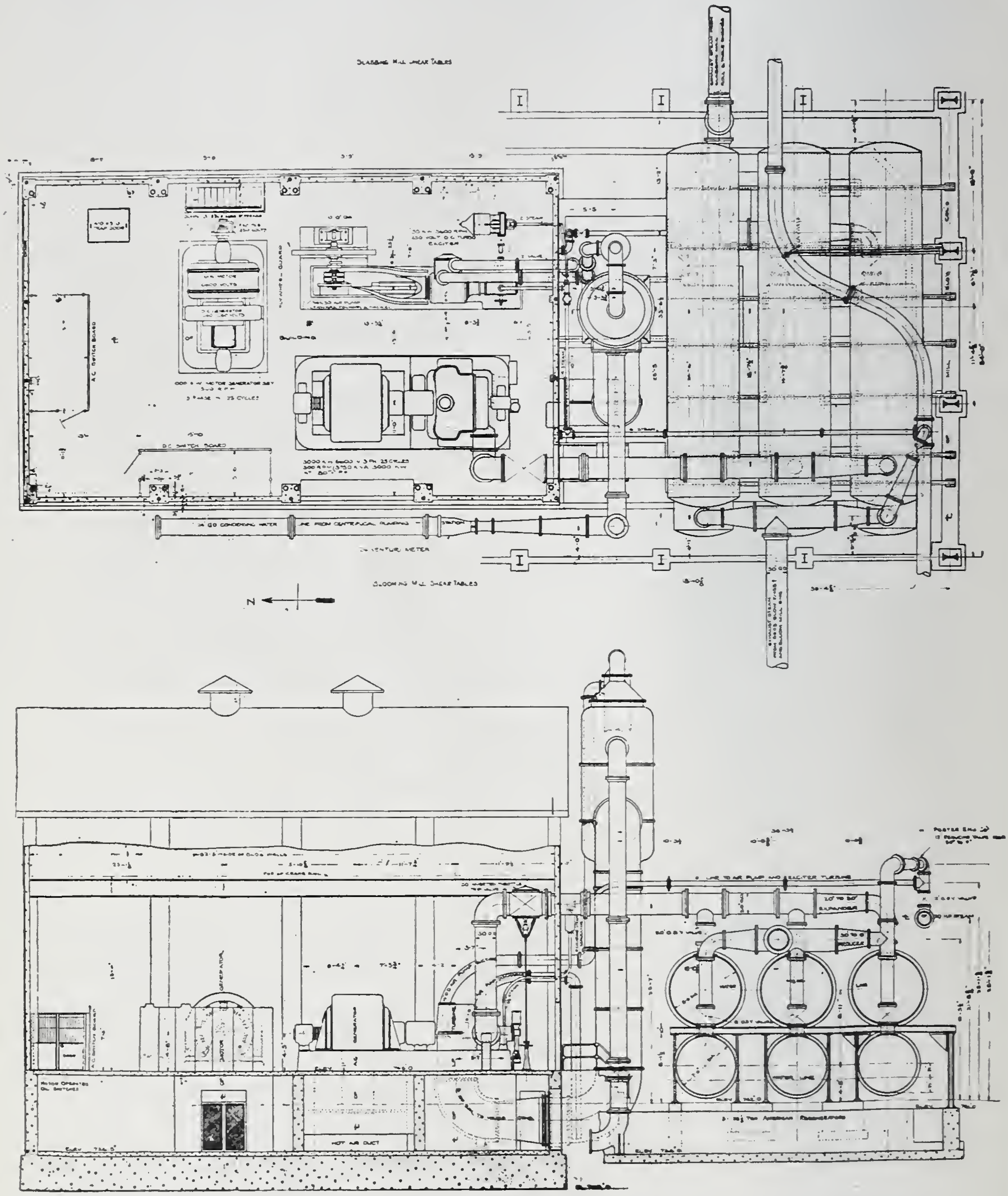


Fig. 8. General Arrangement of Low Pressure Turbine Station.

water in circulation per minute was 22 744 lb. and the quantity of heat stored was 1 814 245 B. t. u.

Regenerative Period: The time required to abstract this heat at the rate of 567 lb. of steam per minute was 166 seconds. This test rather than showing the condition of regular operation, exhibits the possibilities of the regenerator when carried below atmospheric pressure.

Test No. 5

Accumulative Period: Steam was supplied to the regenerator for three minutes. The initial temperature of the water

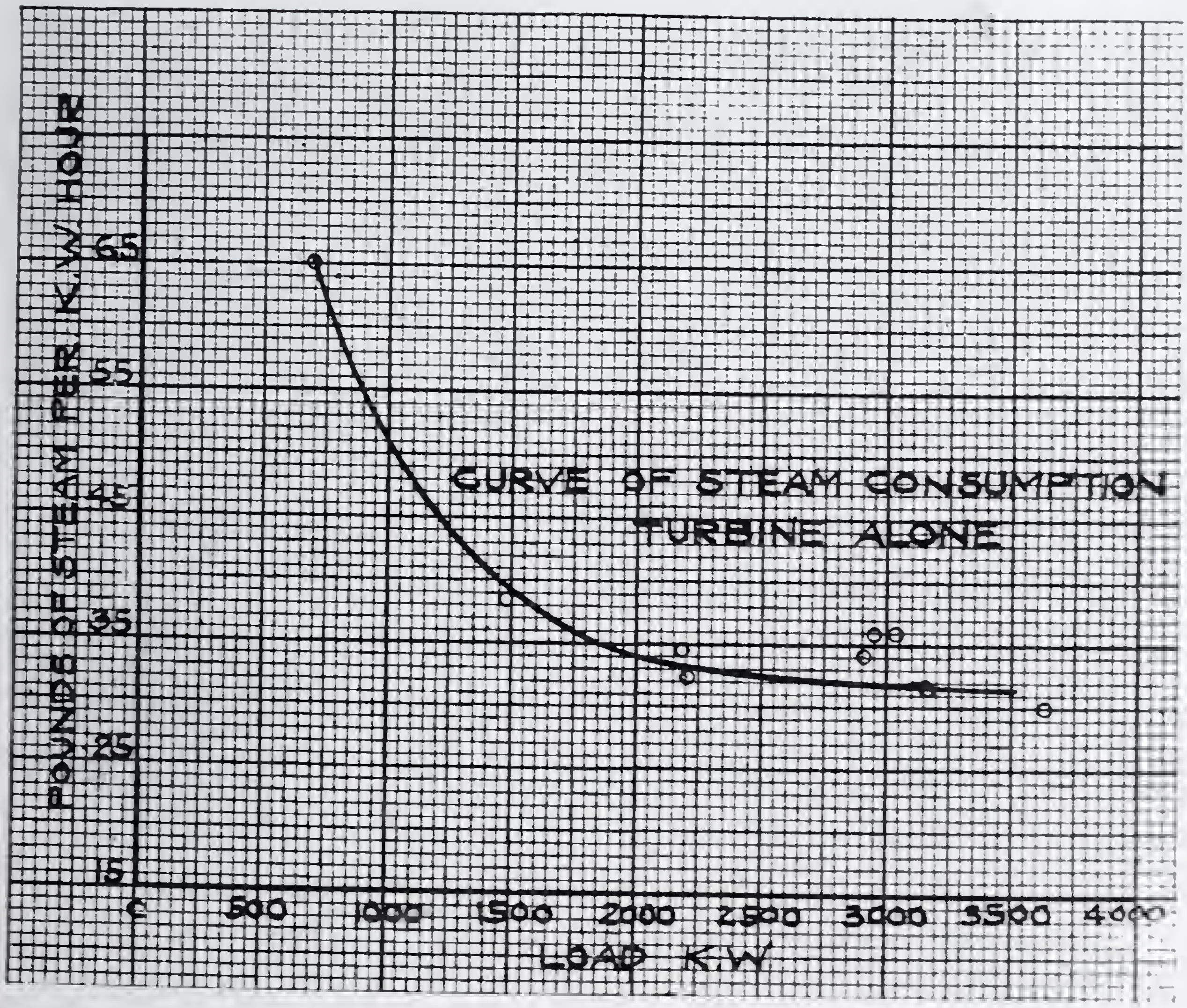


Fig. 9. Curve of Steam Consumption of Turbine Alone.

was 210.3 deg. Fahr., and the final temperature was 219.8 deg., with the steam at a temperature of 234.1 deg. The amount of water in circulation per minute was 15 174 lb., and the quantity of heat stored was 863 653 B. t. u.

Regenerative Period: The time required to abstract the heat at the rate of 567 lb. of steam per minute was 79.29 seconds.

Test No. 6

Accumulative Period: Steam was supplied to the regenerator for three minutes. The initial temperature of the water was 195.0 deg. Fahr., and the final temperature was 212.8 deg., with the steam at a temperature of 231.2 deg. The amount of

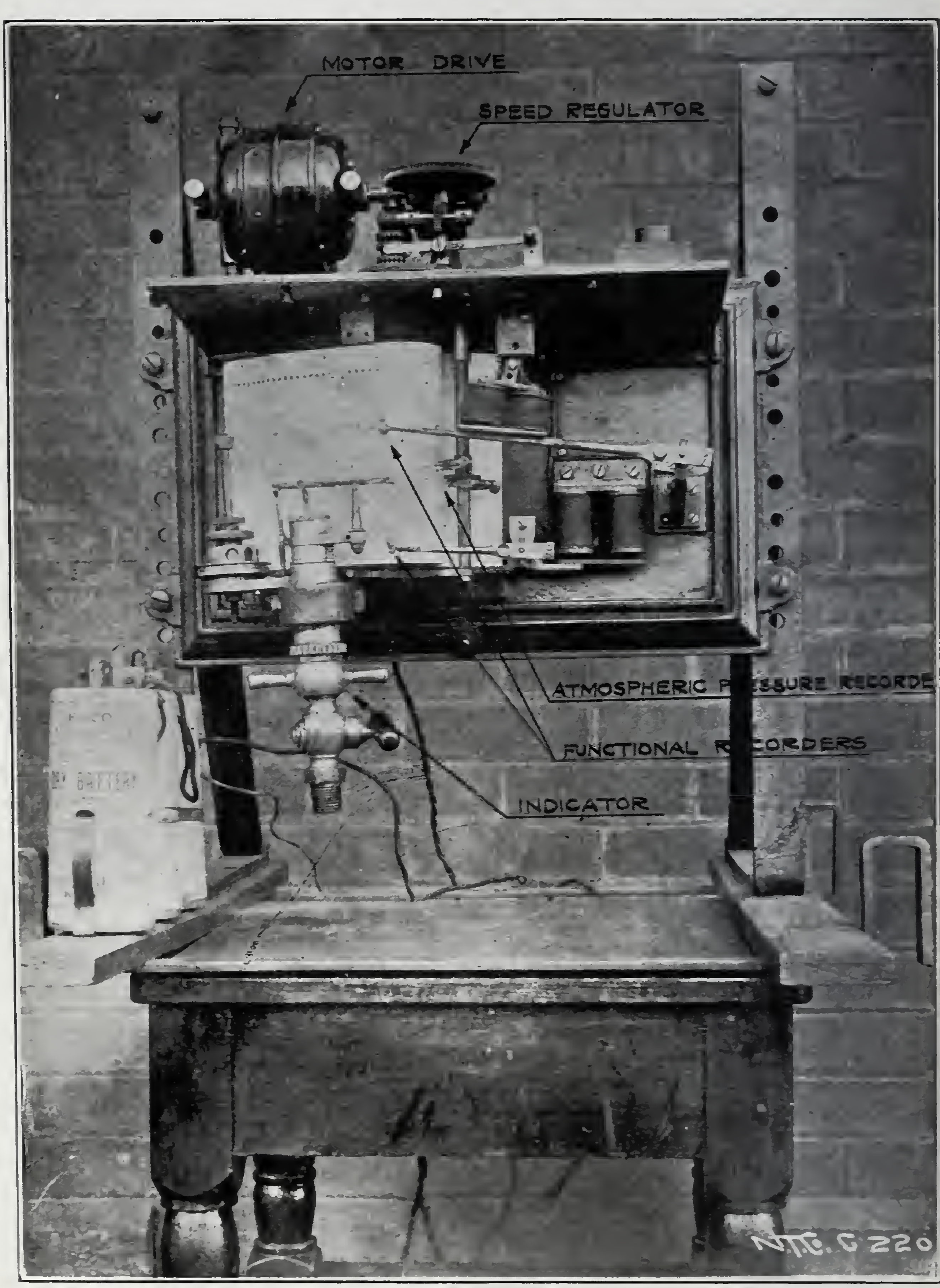


Fig. 10. Automatic Recording Machine for Taking Pressure—Time Charts.

water in circulation per minute was 20 180 lb., and the quantity of heat stored was 1 612 865 B. t. u.

Regenerative Period: The time required to abstract this heat at the rate of 567 lb. of steam per minute was 151.87 seconds. This test also shows the possibilities of the regenerator by working below atmospheric pressure rather than regular operating conditions.

DESCRIPTION OF TURBO-GENERATOR EQUIPMENT

The low pressure turbine station, shown in Fig. 8, is located between the blooming and slabbing mills and contains one Curtis low pressure turbo-generator, one General Electric motor-generator set, one small General Electric turbo-generator for the generation of continuous current for excitation, switchboard and a Weiss dry air pump. In the main power station, located about 2000 feet away, are two General Electric motor generator sets which are tied in electrically and part of this equipment.

The low pressure turbine is a Curtis horizontal, three stage, impulse type rated at 3000 k.w., 1500 r.p.m. and Form *E*, designed to run condensing and deliver its rated capacity with an initial pressure of 16 lb. absolute. It is directly connected to the generator which is rated as Type *A. T. B.* 2-pole, 3000 k.w., 1500 r.p.m., 6600 volts, 3 phase, 25 cycles. With a power factor of 100 percent, the generator is designed to develop 3750 k.v.a. or an actual energy output of 3000 k.w. at 80 percent power factor. The turbine exhausts into a Weiss barometric counter current condenser, of self supporting type with a rated capacity of condensing one hundred and fifty thousand pounds of steam per hour. The Weiss dry air pump for this condenser is a 13 inch by 34 inch horizontal tandem pump with a ratted speed of 55 r.p.m. The cooling water for the condenser is furnished through a 24 in. line from the pump located about eight hundred feet away. There are two 16 in. horizontal motor driven centrifugal pumps with a combined capacity of 12 000 gal. of water per minute. Each is directly connected to a 150 h.p., 230 volts, 540 amperes, direct current Garwood Electric Company motor running at 500 r.p.m.

The alternating current from the turbo-generator is con-

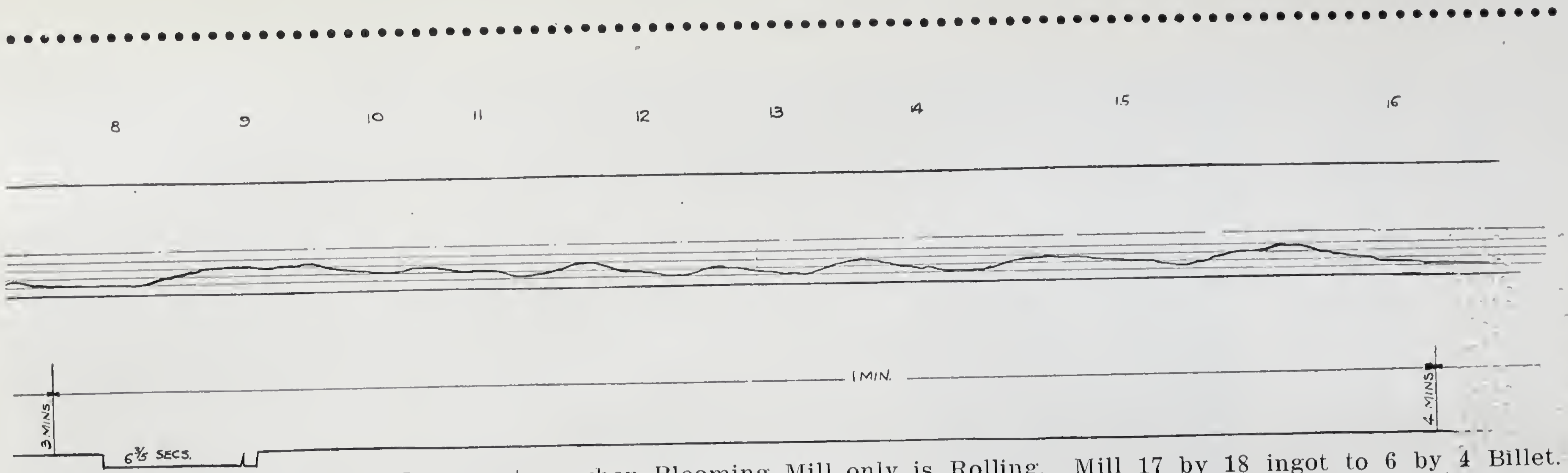


Chart No. 1. Pressure in Regenerators when Blooming Mill only is Rolling. Mill 17 by 18 ingot to 6 by 4 Billet. Scale of Spring: 1 in. = 10 lb.

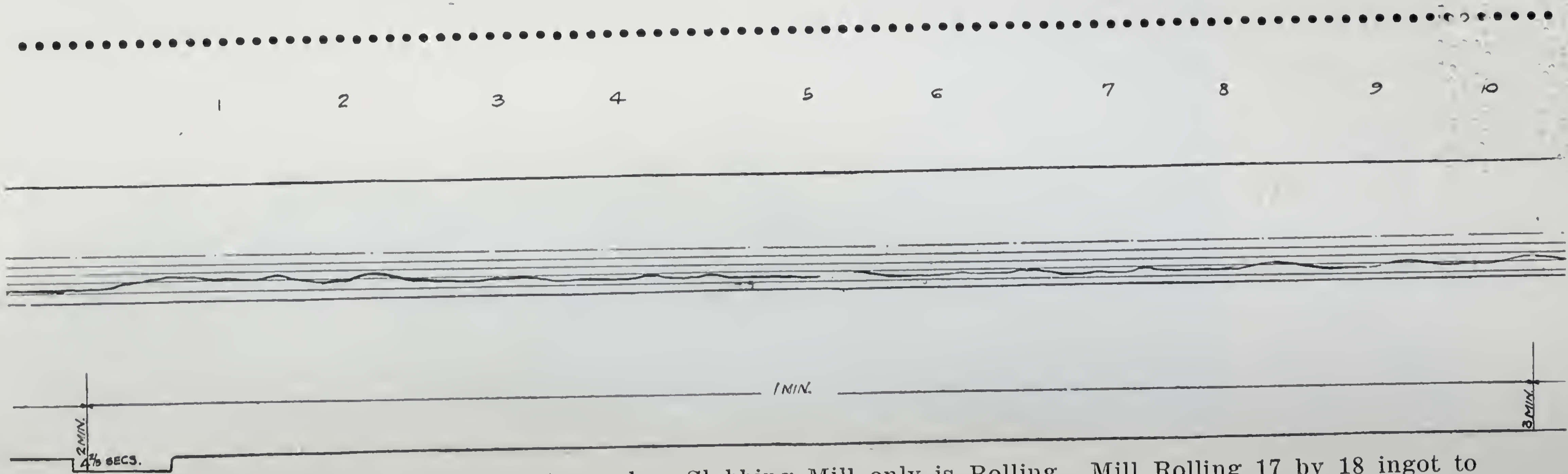


Chart No. 2. Pressure in Regenerators when Slabbing Mill only is Rolling. Mill Rolling 17 by 18 ingot to 4 by 13⅜ Slab. Scale of Spring: 1 in. = 10 lb.

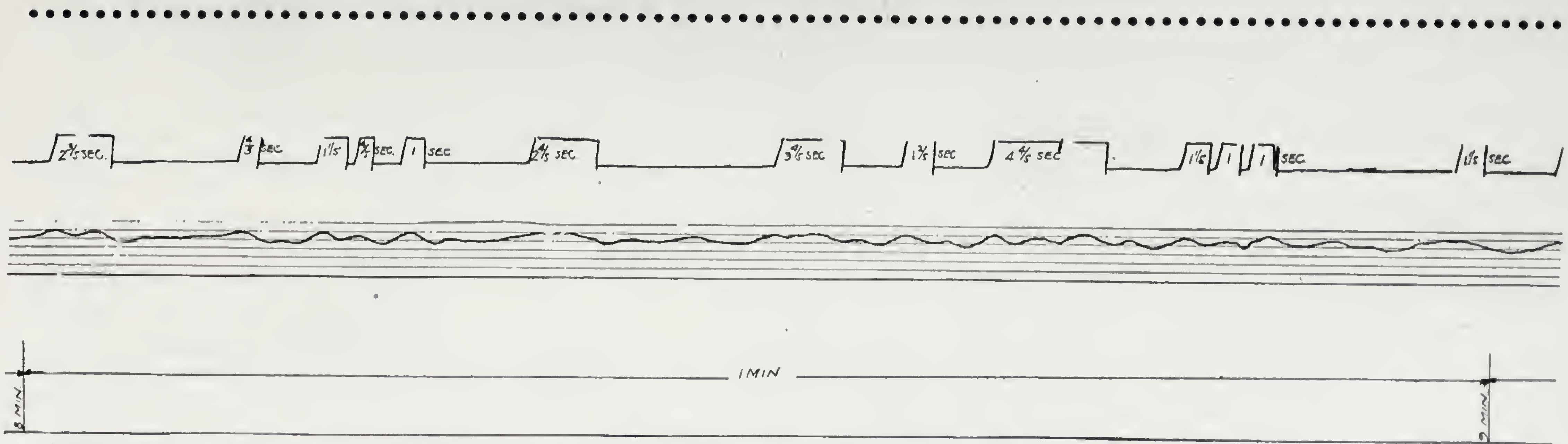


Chart No. 3. Pressure in Regenerators when Blooming and Slabbing Mill are Rolling at the same time. Slabbing Mill Rolling 17 by 18 Ingot to 4 by 13⅜ Slab. Blooming Mill Rolling 17 by 18 Ingot to 4 by 6 Billet. Scale of Spring: 1 in. = 10 lb.

verted to direct current by the motor generators, one in the turbine station and two in the main power station. These sets are all the same size and make, namely, General Electric two unit, two bearings, with synchronous motor and direct current generator. The synchronous motor is a 25 cycle, 3 phase, Type *A. T. I.*, 6 pole, 1060 k.w., 500 r.p.m., 6600 volts and the direct current generator is a Type *M. P. C.*, 10 pole, 1000 k.w., 500 r.p.m., 240-260 volts and 3250 amperes.

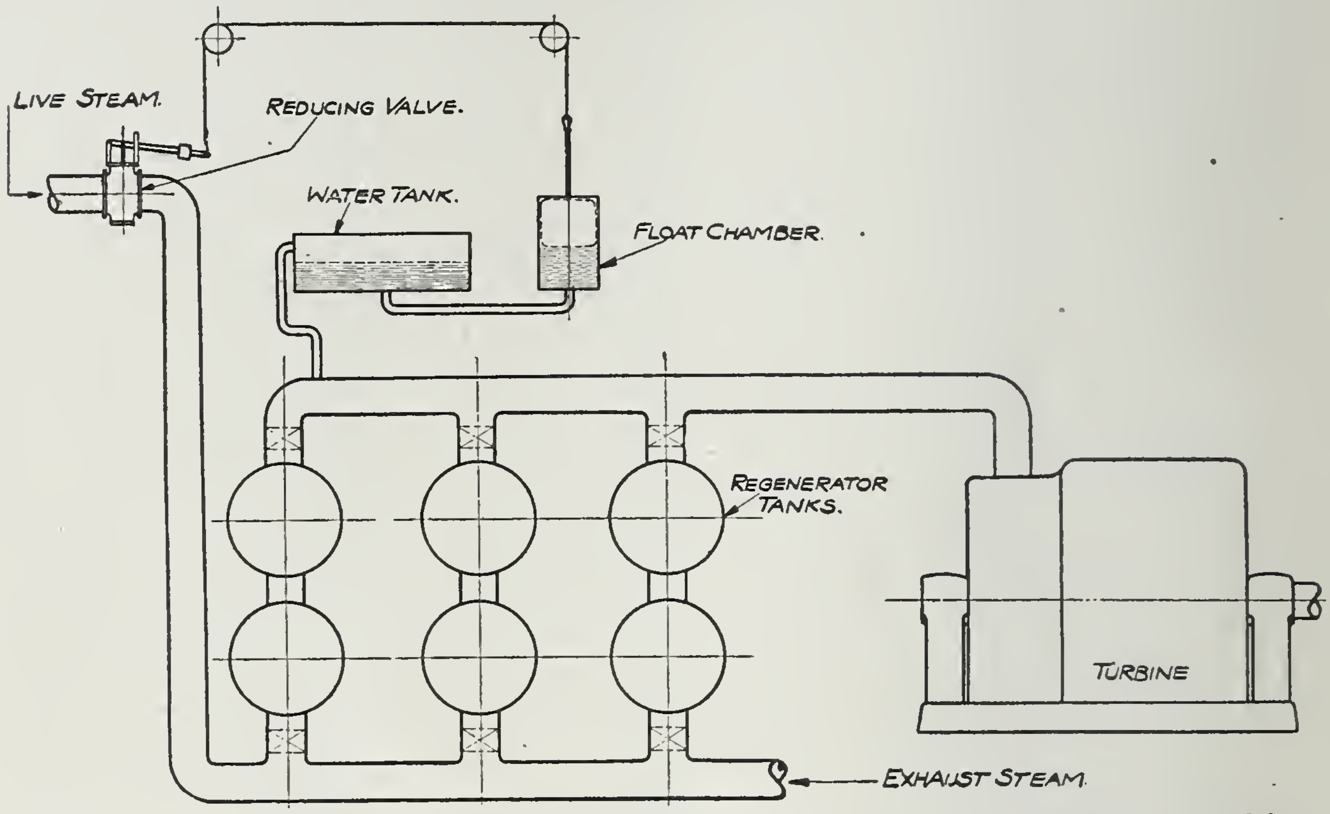


Fig. 11. Diagram of Pressure Regulator for Low Pressure Turbine.

The admission of steam is controlled by a governor of the centrifugal type mounted on a vertical shaft. The motion of the governor weights is transmitted through a lever supported on roller bearings to the pilot valve of the hydraulic cylinder; oil is admitted under pressure to this cylinder which operates a thirty inch butterfly throttling valve in the inlet line of the turbine.

Emergency appliances are provided for as follows: An independent emergency overspeed governor, which acts on a trip steam valve, is located in the inlet steam line before the throttle valve, and this governor is also connected to operate the throttle valve and an eight inch vacuum breaker. All three devices are inter-connected so as to operate simultaneously in case of overspeeding of the turbine. All contrivances, or any

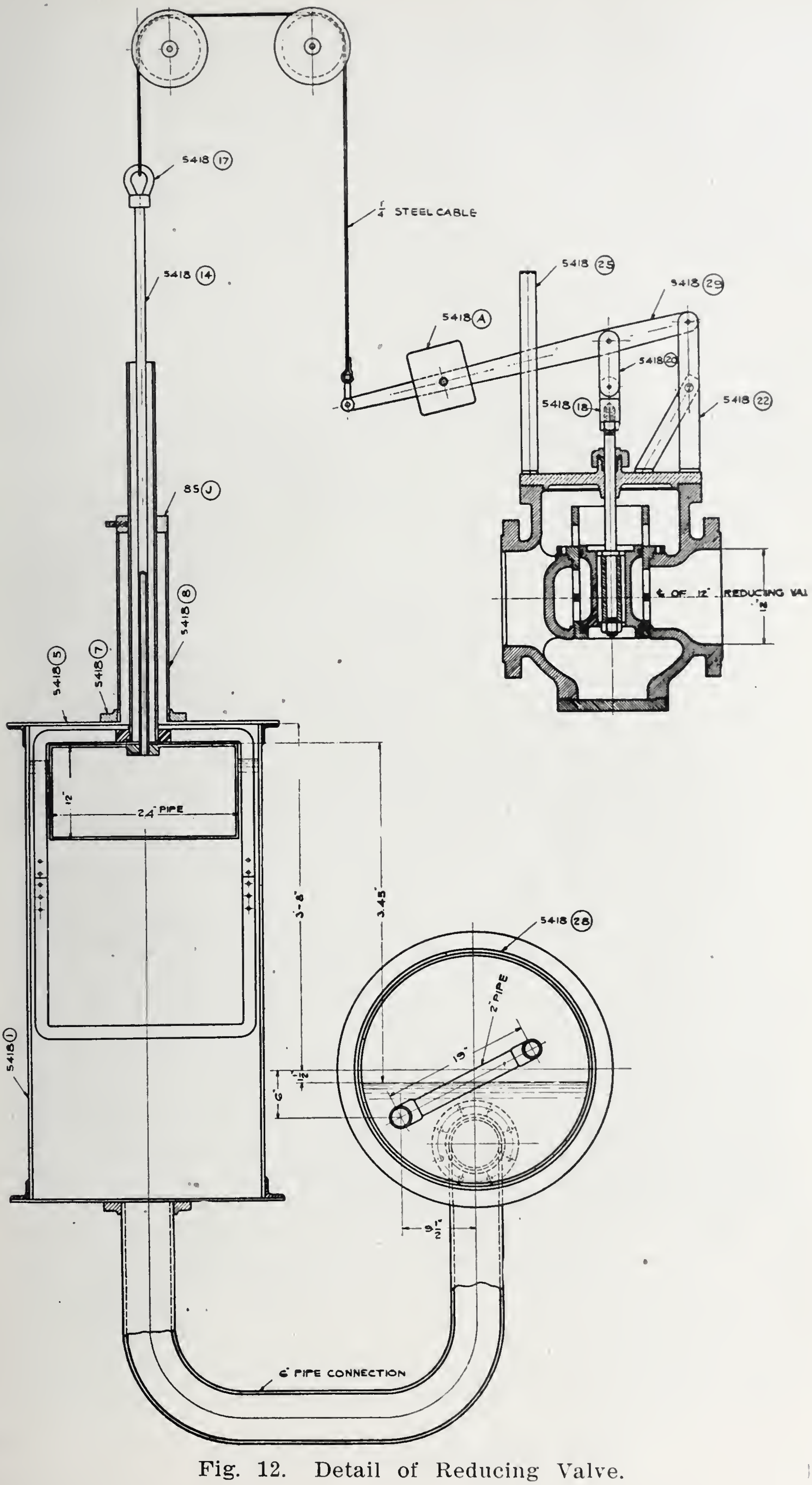
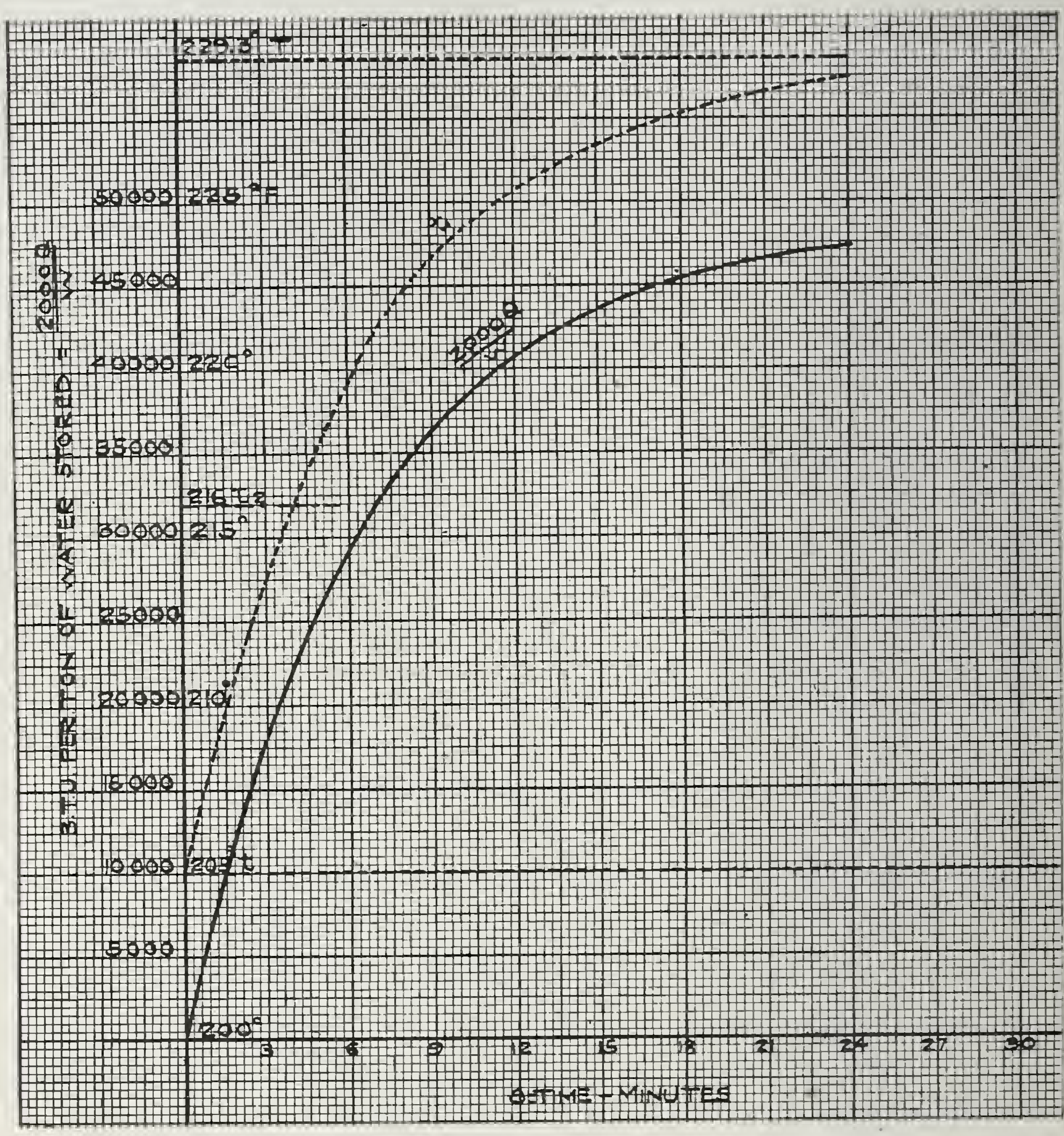


Fig. 12. Detail of Reducing Valve.

one, may be tripped by hand to stop the turbine, and should these fail of operation a glass cover plate, wire protected, may be smashed in order to break the vacuum. All emergency appliances are so designed that it is necessary to properly set them in position before the turbine can be started.

TURBINE TESTS

These tests were run to determine the steam consumption of the turbine at various loads and were made as follows:



Test No. 1. Accumulative Period.
Regenerator No. 2 at Turbine Station.

$\theta = 4.0$

$\Delta = 0.151$

$t_1 = 205.0$

$t_2 = 216.0$

$T = 229.3$

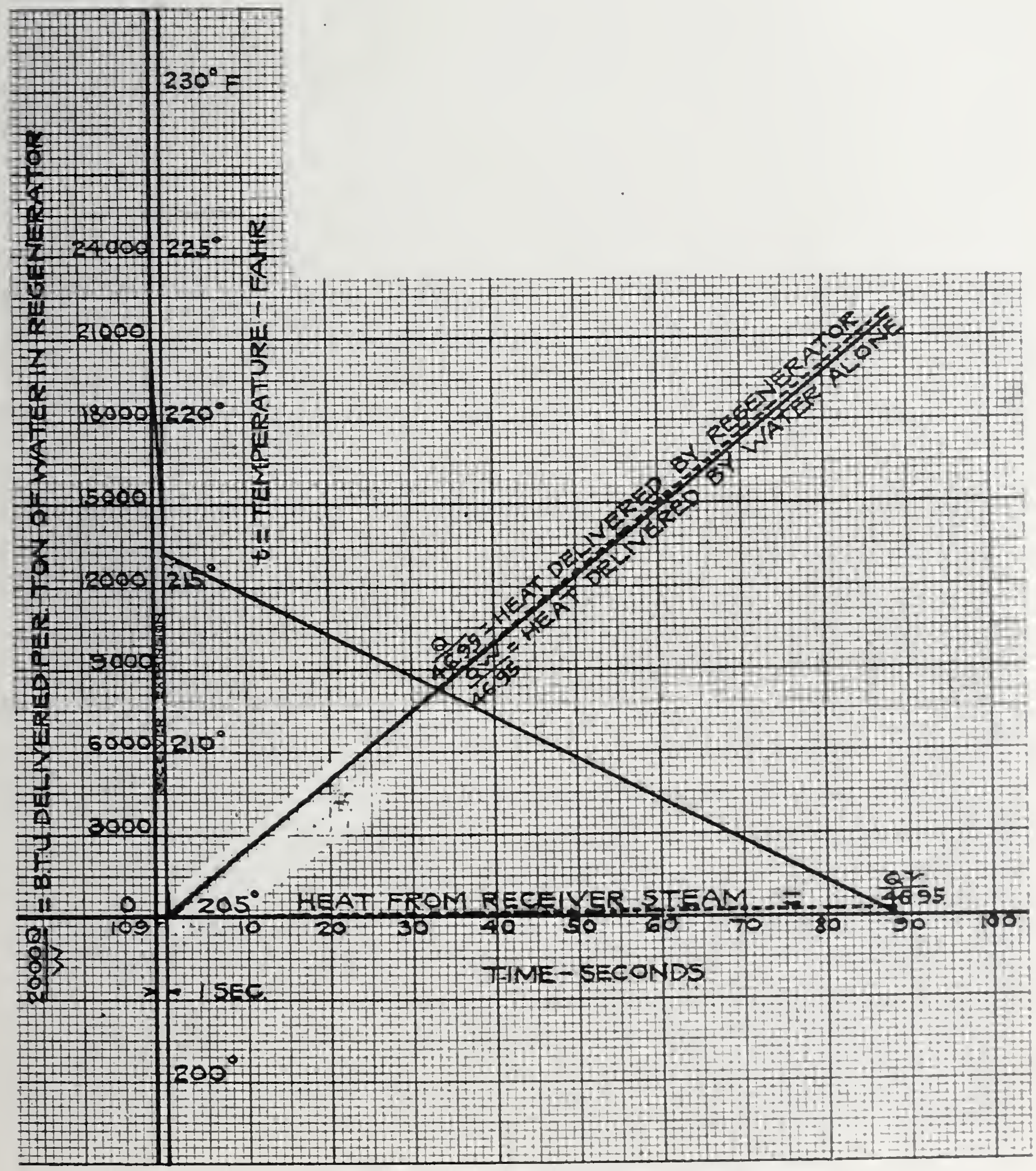
$$t = 229.3 - \frac{24.3}{\epsilon^{0.151\,\theta}}$$

$$\frac{2000\ Q}{W} = 48\,600 \left(1 - \frac{1}{\epsilon^{0.151\,\theta}}\right)$$

All gauges, thermometers, meters and measuring instruments were calibrated before and after the test, and corrections applied to the readings.

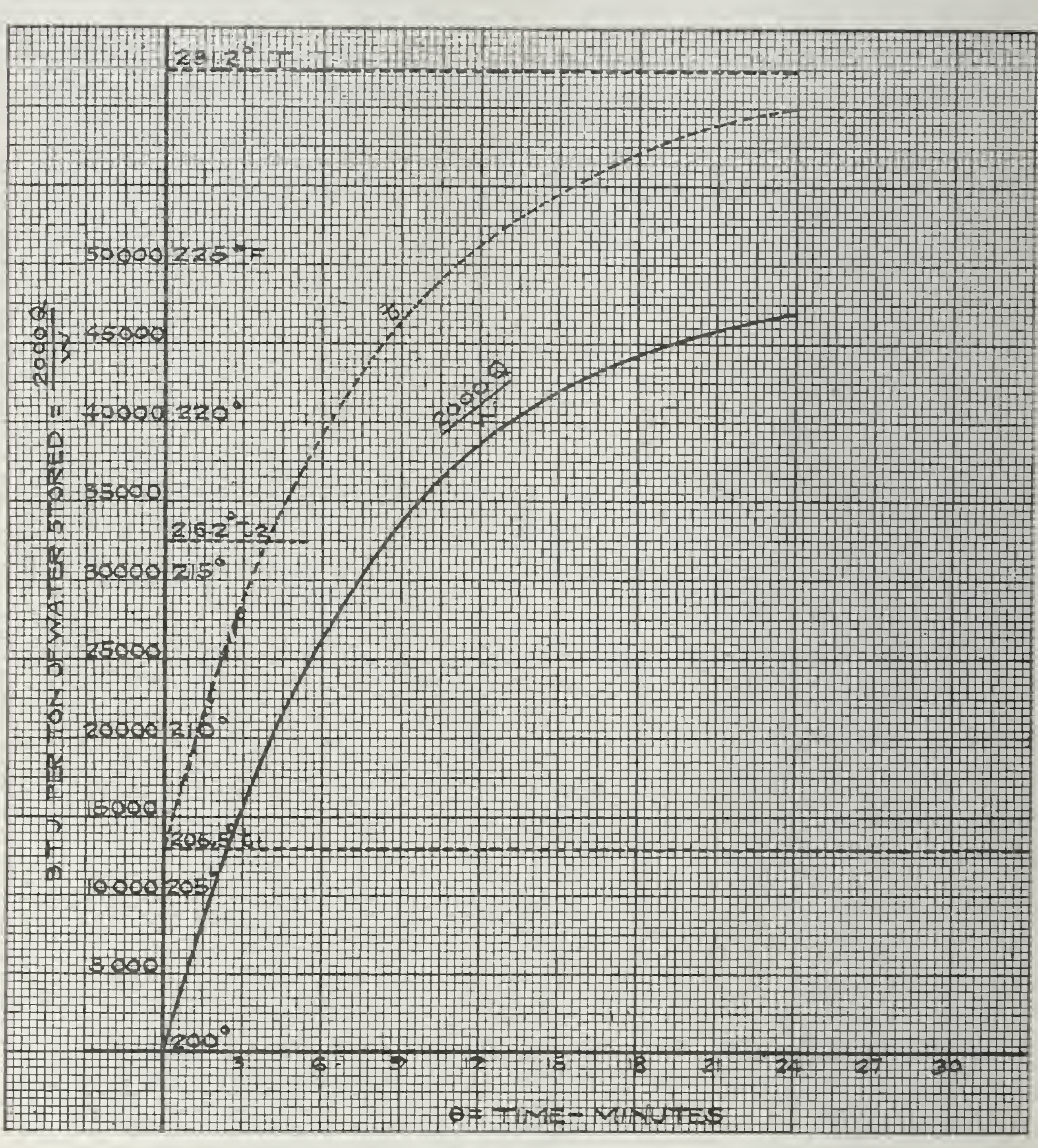
The steam pressure at the throttle was taken with a low pressure gauge and the vacuum in the condenser was taken with a mercury column. These readings were observed every five minutes.

The atmospheric pressure was observed every fifteen minutes from a standard barometer of the observatory type and the readings referred to a standard barometer of 30 in.



Test No. 1. Regenerative Period.
Regenerator No. 2 at Turbine Station.

The circulating water was measured by a 24 inch by 12 inch Venturi meter tube, the differential pressure being registered by a mercury manometer. The temperature of the circulating water was taken by a thermometer located in the inlet pipe close to the condenser and the temperature of the tail water was taken with a thermometer located in the tail pipe. These readings were observed at five minute intervals.



Test No. 2. Accumulative Period.
Regenerator No. 2 at Turbine Station.

$\theta = 4.0$

$\Delta = 0.125$

$t_1 = 206.5$

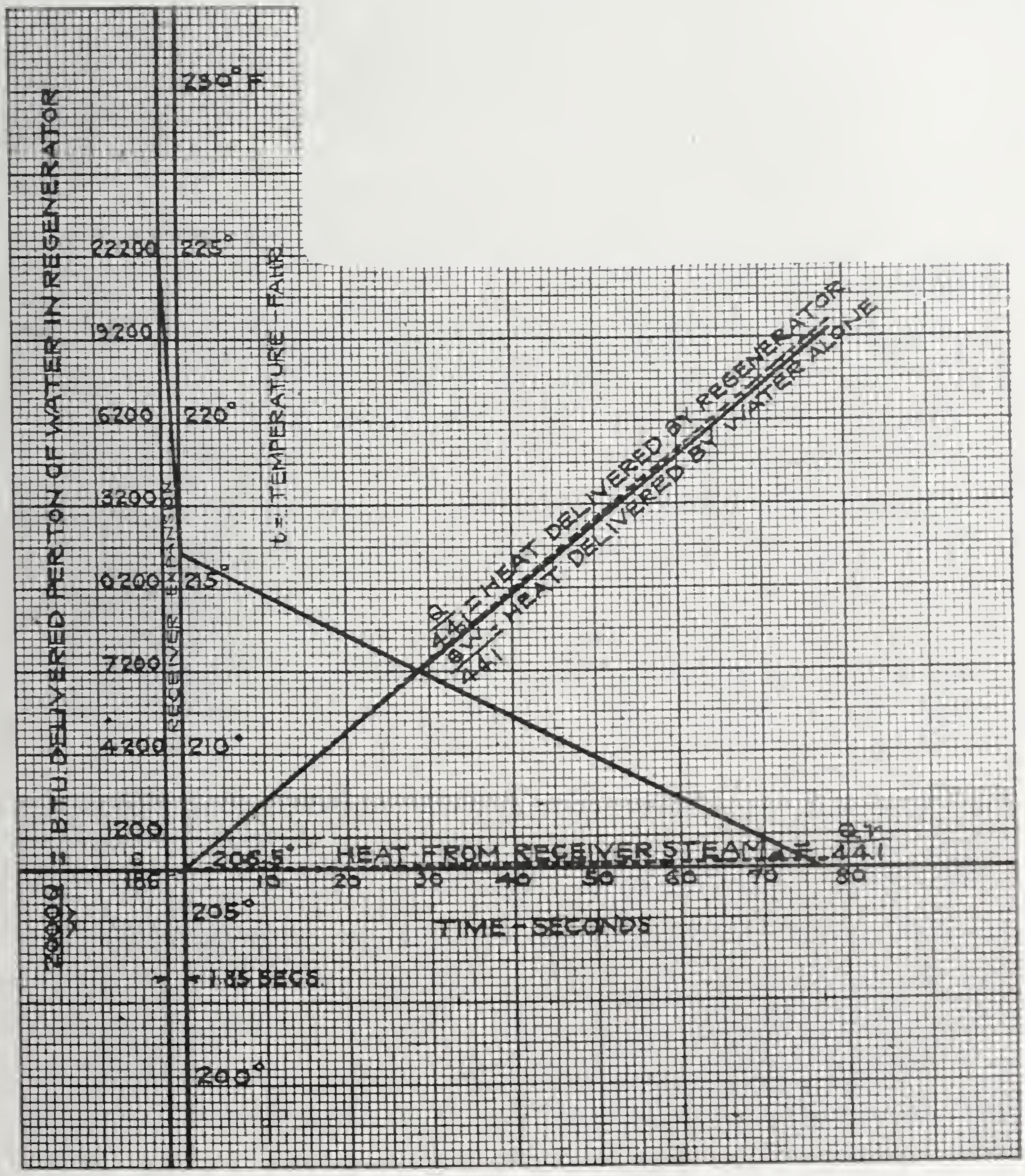
$t_2 = 216.2$

$T = 231.2$

$$t = 231.2 - \frac{24.7}{\epsilon^{0.125\,\theta}}$$

$$\frac{2000\,Q}{W} = 49\,400\left(1 - \frac{1}{\epsilon^{0.125\,\theta}}\right)$$

The quality of the steam was obtained by a throttling, evaporating calorimeter located in the steam main close to the turbine. This is a combination throttling and separating calorimeter so designed that in case all the moisture is not removed by evaporation, what remains will be registered by the separating calorimeter. The sampling nozzle used was a standard A. S. M. E. nozzle, and the discharge end of the calorimeter was connected to the condenser air pump. A nozzle the same as that described by Mr. Stott in the A. S. M. E. Transc. Vol. 32, page 77, was also tried, but no appreciable difference could be found in the sampled steam. A series of tests were run to de-



Test No. 2. Regenerative Period.
Regenerator No. 2 at Turbine Station.

termine the quality of this low pressure steam, the percentage of moisture remained practically the same; in all cases the moisture was taken care of by the throttling calorimeter, no moisture being deposited in the separating chamber at any time.

All meters for electrical measurements were read at five minute intervals. The load on the turbine was maintained constant by motoring various electric generator units, by an electric light load and by a water rheostat.

The heat lost due to radiation was made up of heat lost from the turbine body and steam piping. An allowance was made of 3.2 B. t. u. per square foot per hour per degree difference in temperature. The heat to work was figured by using the heat equivalent of one horsepower as 42.416 B. t. u. per minute. The heat rejected was obtained by considering the condenser as a large calorimeter.

In Table No. 1 is shown the data and results of the turbogenerator tests, and in Fig. 9 is shown graphically the steam consumption per k.w. hour.

The net results obtained by the installation of the low pressure turbine and regenerators were as follows:

First: An increase of 57.5 percent in the rated electrical capacity of the plant.

Second: The back pressures, in pounds per square inch, on the blooming and slabbing engines was as follows:

	Operating Alone		Operating Together		Before Turbine Installation	
Engines	Average	Maximum	Average	Maximum	Average	Maximum
Blooming Mill	3.77	10.00	7.35	10.00	1.50	5.30
Slabbing Mill	5.04	10.06	7.82	11.00	1.10	6.20

Third: The load on the turbine is such that the steam consumption of the turbine is practically constant. When only the blooming engine is operating, the supply of exhaust steam, which is approximately 76 000 lb. per hour, is insufficient to meet the demands of the turbine and in order to provide this deficiency, the live steam valve is open about 10.5 minutes per hour. When only the slabbing mill engines are operating, live steam is admitted to the turbine about 2.6 minutes per hour, exhaust steam from these engines being approximately 100 000 lb. per hour. In either of the above cases it is very seldom that

any exhaust steam escapes to the atmosphere. When both mills are operating at the same time, the exhaust steam is much in excess of the demand, and the relief valves are open about 18.9 minutes per hour, discharging the excess steam to the atmosphere.

This data was obtained by means of the automatic recording machine shown in Fig. 10. This machine consists of an ordinary steam engine indicator with a light spring. The recording chart is driven by a motor and has a gear reduction by means of which two speeds of the chart may be obtained. Two recording pens operated by electric magnets are used, one to record any movement of the relief valves exhausting steam to the atmosphere and one to record the movement of the live steam reducing valve admitting steam to the regenerator.

On Chart No. 1 is shown the general operating conditions when only the blooming mill engine is running and exhausting into the regenerators. As can be seen by this chart, no breaks occur in the top line which would indicate the opening of the relief valves and the discharge of steam to the atmosphere. The center line indicates the pressure in the regenerator, each scaled division denoting one pound pressure per square inch; and a break in the bottom line indicates the opening of the live steam valve and the admittance of steam to the regenerators.

On Chart No. 2 is shown the general operating conditions when only the slabbing mill engines are running.

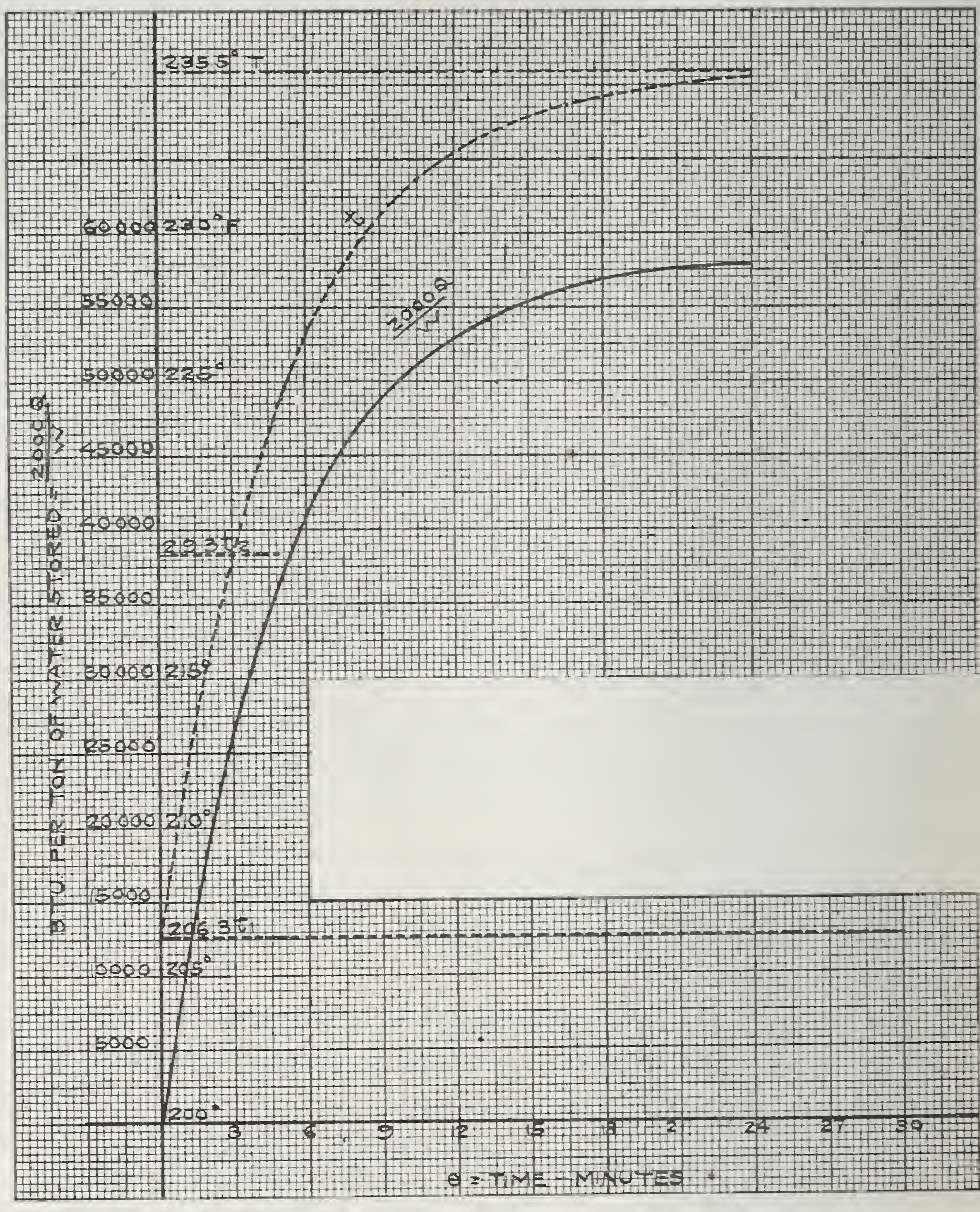
On Chart No. 3 is shown the general operating conditions when the blooming mill and slabbing mill engines are running at the same time.

On the top of each chart the roll passes are indicated by number; these were placed by an observer and not automatically recorded like the rest of the events.

OPERATING DIFFICULTIES ENCOUNTERED

When the low pressure turbine and regenerators were first put into service there were several details operating unsatisfactorily, the most serious of which was the reducing valves. As this is a straight low pressure turbine it is imperative that the reducing valve be absolutely reliable and positive in its performance.

The first valve used was a 12 in. Foster reducing valve designed to open at 15 lb. and close at 15.5 lb. absolute pressure. From the beginning this valve failed to operate as specified above, it would stick in either closed or open positions. When



Test No. 3. Accumulative Period.
Regenerator No. 2 at Turbine Station.

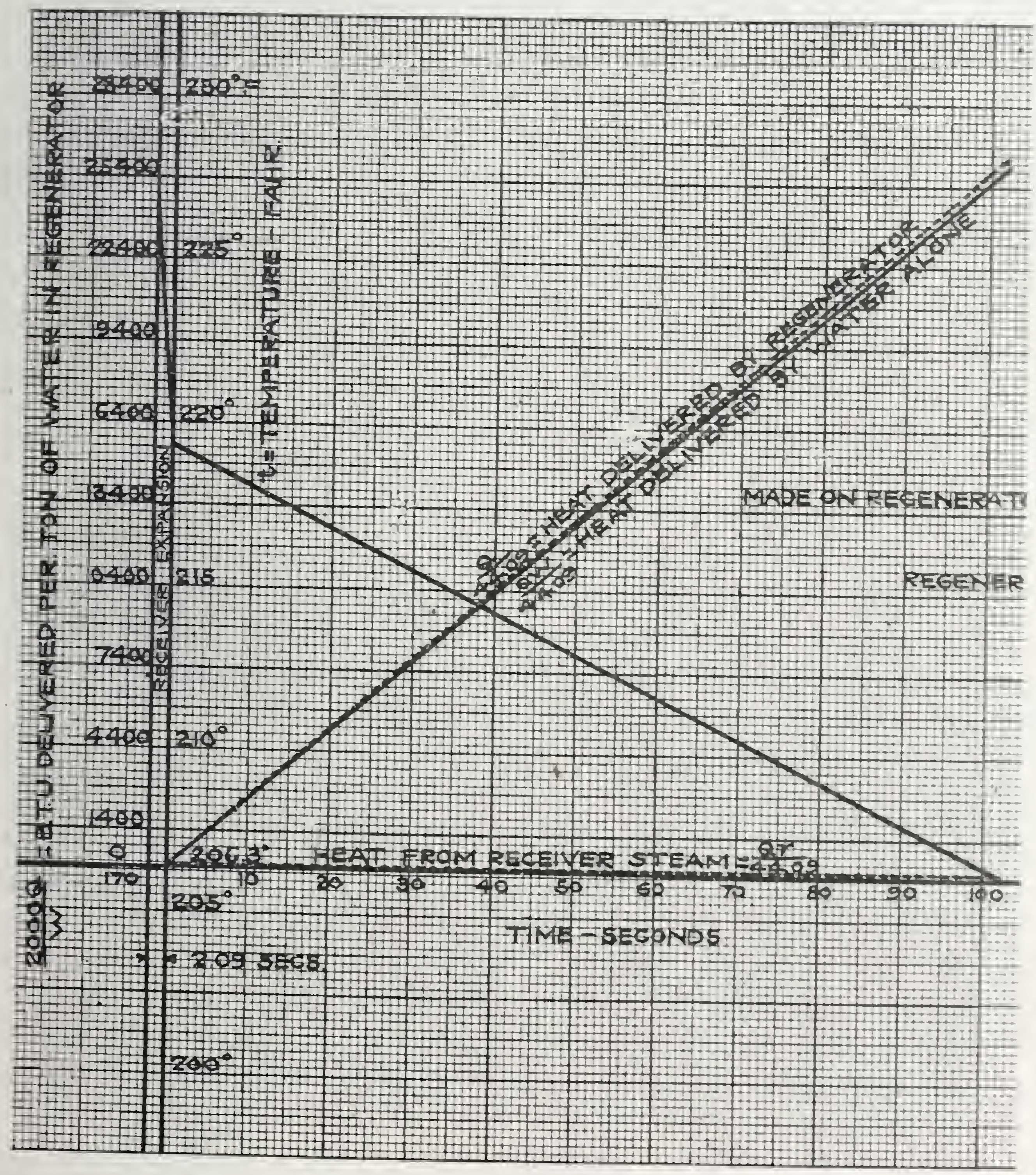
$\theta = 3.0$
$\Delta = 0.197$
$t_1 = 206.3$
$t_2 = 219.3$
$T = 235.5$

$$t = 235.5 - \frac{29.2}{\epsilon^{0.197\,\theta}}$$

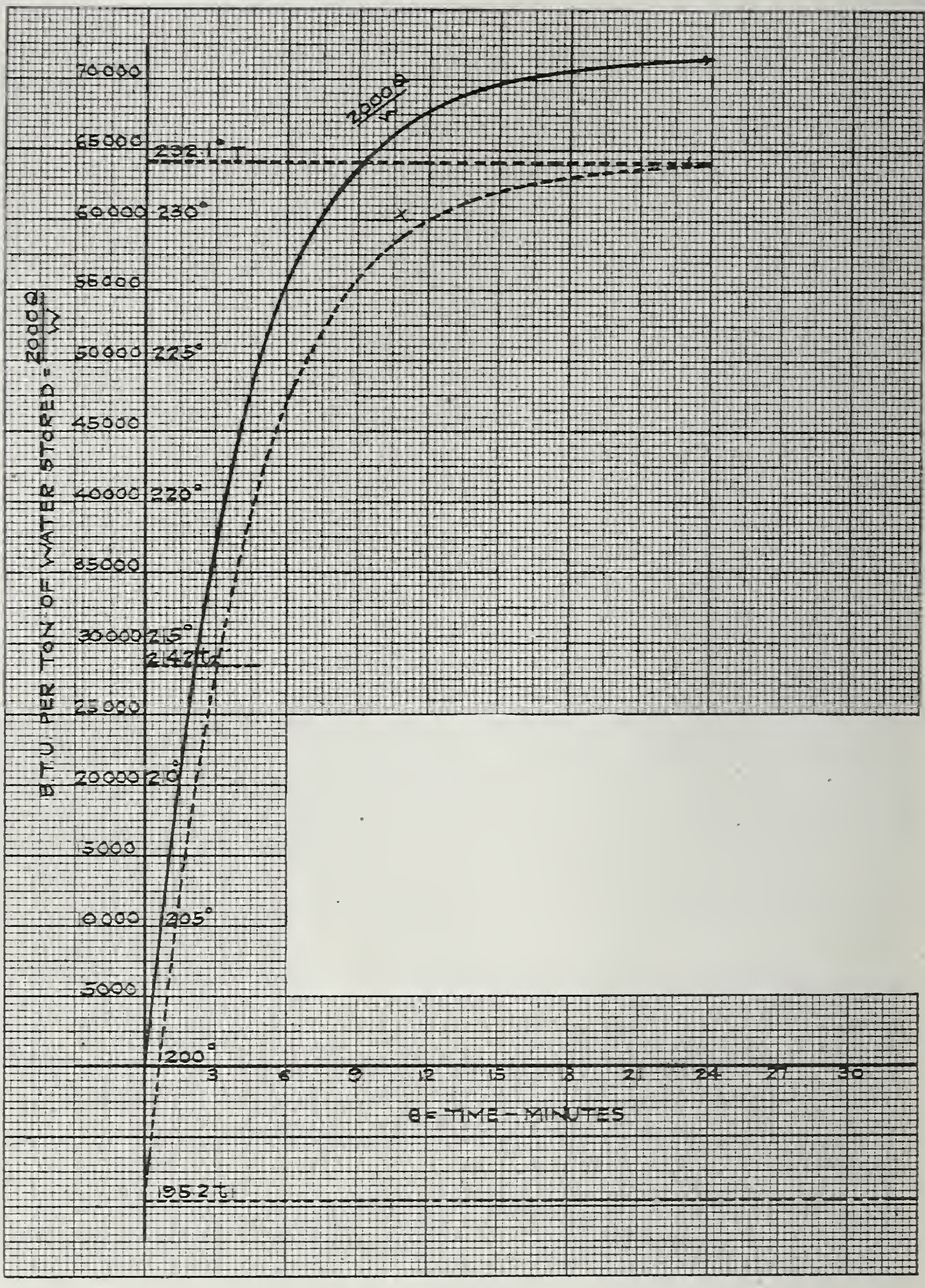
$$\frac{2000\ Q}{W} = 58\,400 \left(1 - \frac{1}{\epsilon^{0.197\,\theta}}\right)$$

the valve would remain closed the turbo-generator would drop its load, which represented over 50 percent of the total power plant output, resulting in a complete loss of voltage and even though this was only of a few moments duration it was a serious condition that had to be remedied. When this valve would stick open the pressure tending to close it would build up and the valve would become so unbalanced that when closing it would do so with sufficient force to wreck itself.

This condition of unsatisfactory operation continued for about seven months, during which time two of these reducing



Test No. 3. Regenerative Period.
Regenerator No. 2 at Turbine Station.



Test No. 4. Accumulative Period.
Regenerator No. 2 at Turbine Station.

$\theta = 3.0$

$\Delta = 0.241$

$t_1 = 195.2$

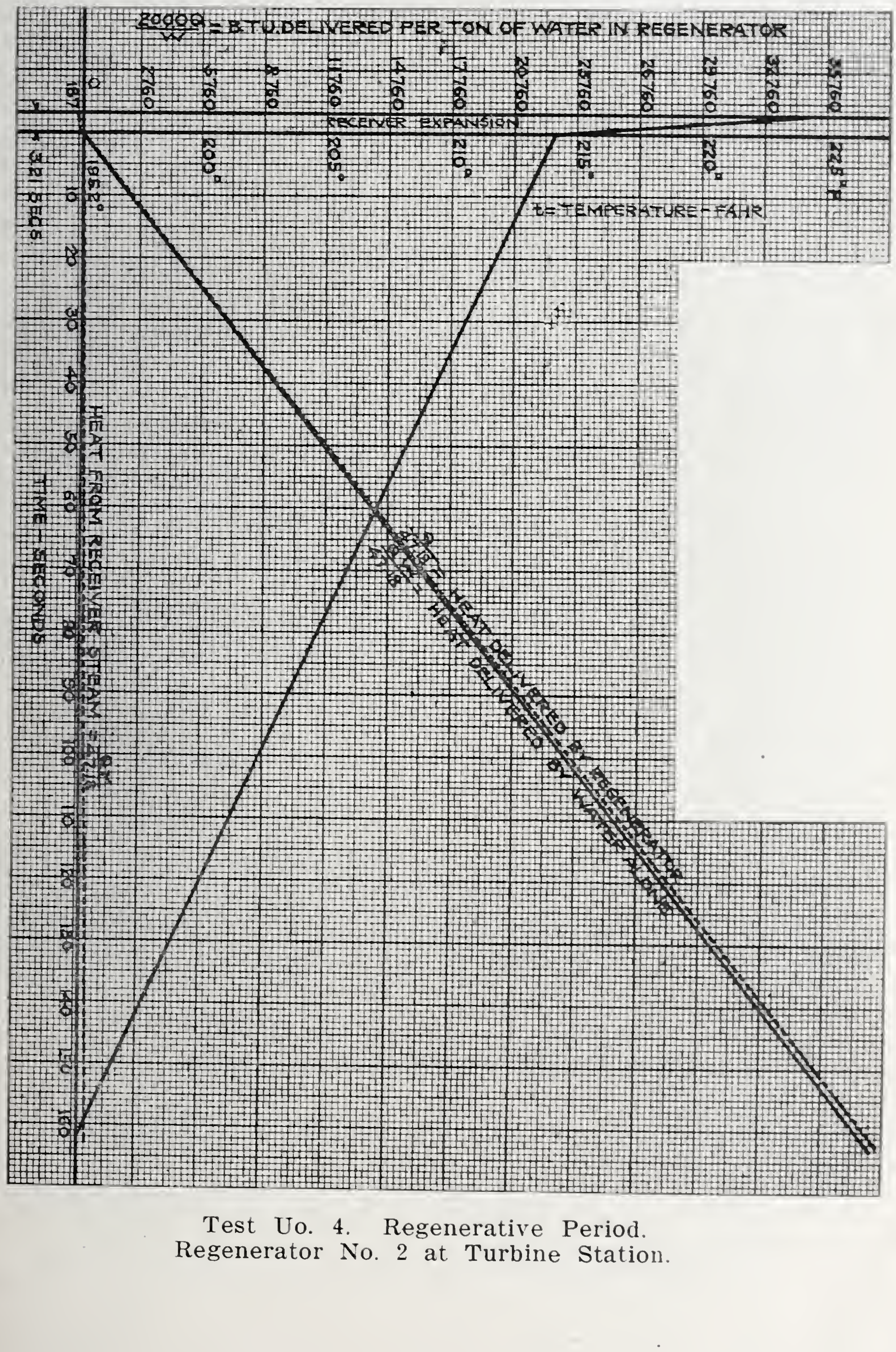
$t_2 = 214.2$

$T = 232.1$

$$t = 232.1 - \frac{36.9}{\epsilon^{0.241\,\theta}}$$

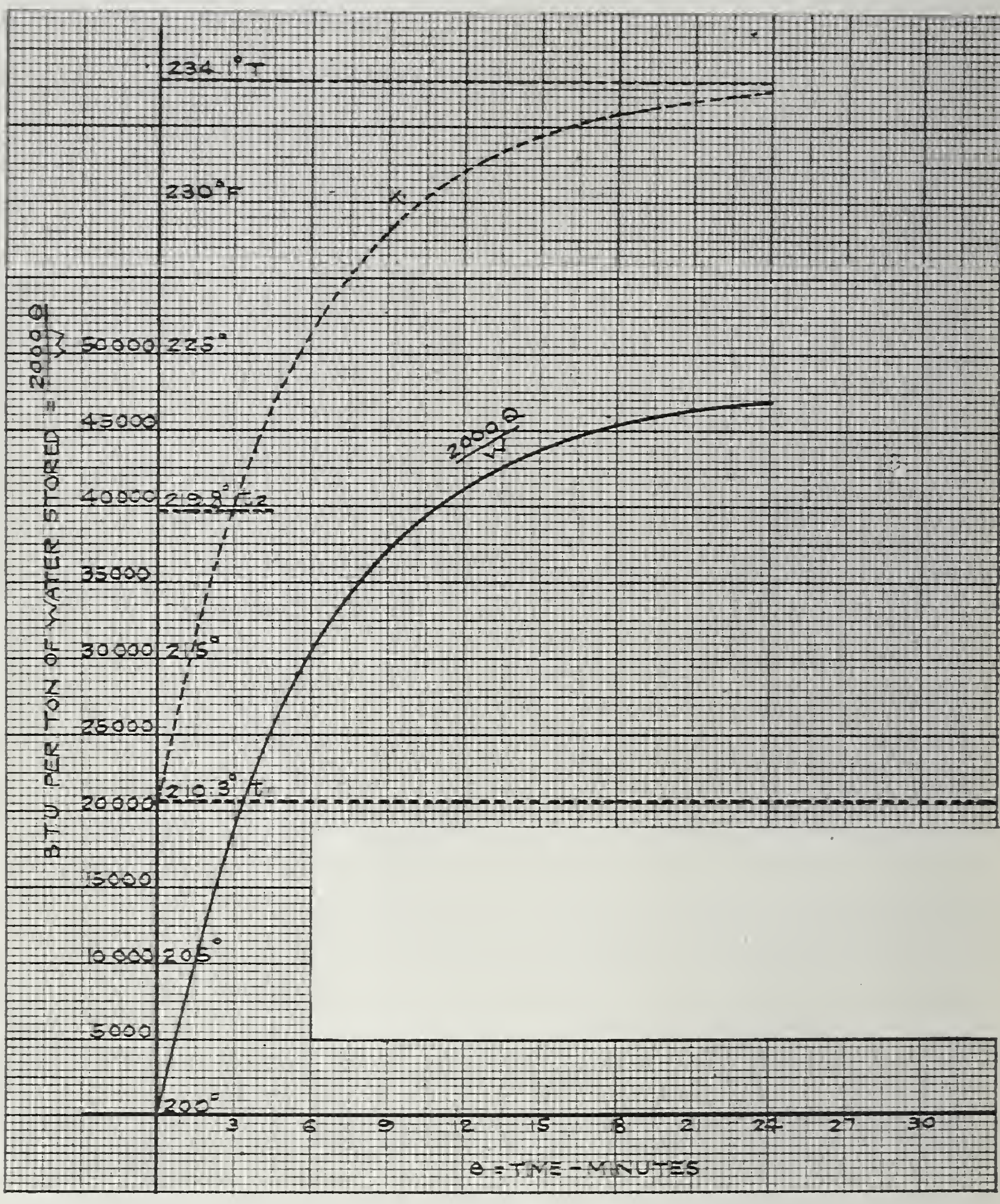
$$\frac{2000\,Q}{W} = 7180\left(1 - \frac{1}{\epsilon^{0.241\,\theta}}\right)$$

valves were completely wrecked, and caused innumerable delays. These troubles were finally overcome by the use of a balanced piston valve, which is positive in its action, being controlled directly by the pressure in the regenerators. A diagramatic arrangement of the controlling apparatus is shown in Fig. 11 and



Test Uo. 4. Regenerative Period.
Regenerator No. 2 at Turbine Station.

the valve in Fig. 12. This valve has been in operation since July, 1912, and with exception of a leak in the float which was repaired in July, 1913, has given complete satisfaction. As



Test No. 5. Accumulative Period.
Regenerator No. 2 at Turbine Station.

$\theta = 3.0$

$\Delta = 0.17$

$t_1 = 210.3$

$t_2 = 219.8$

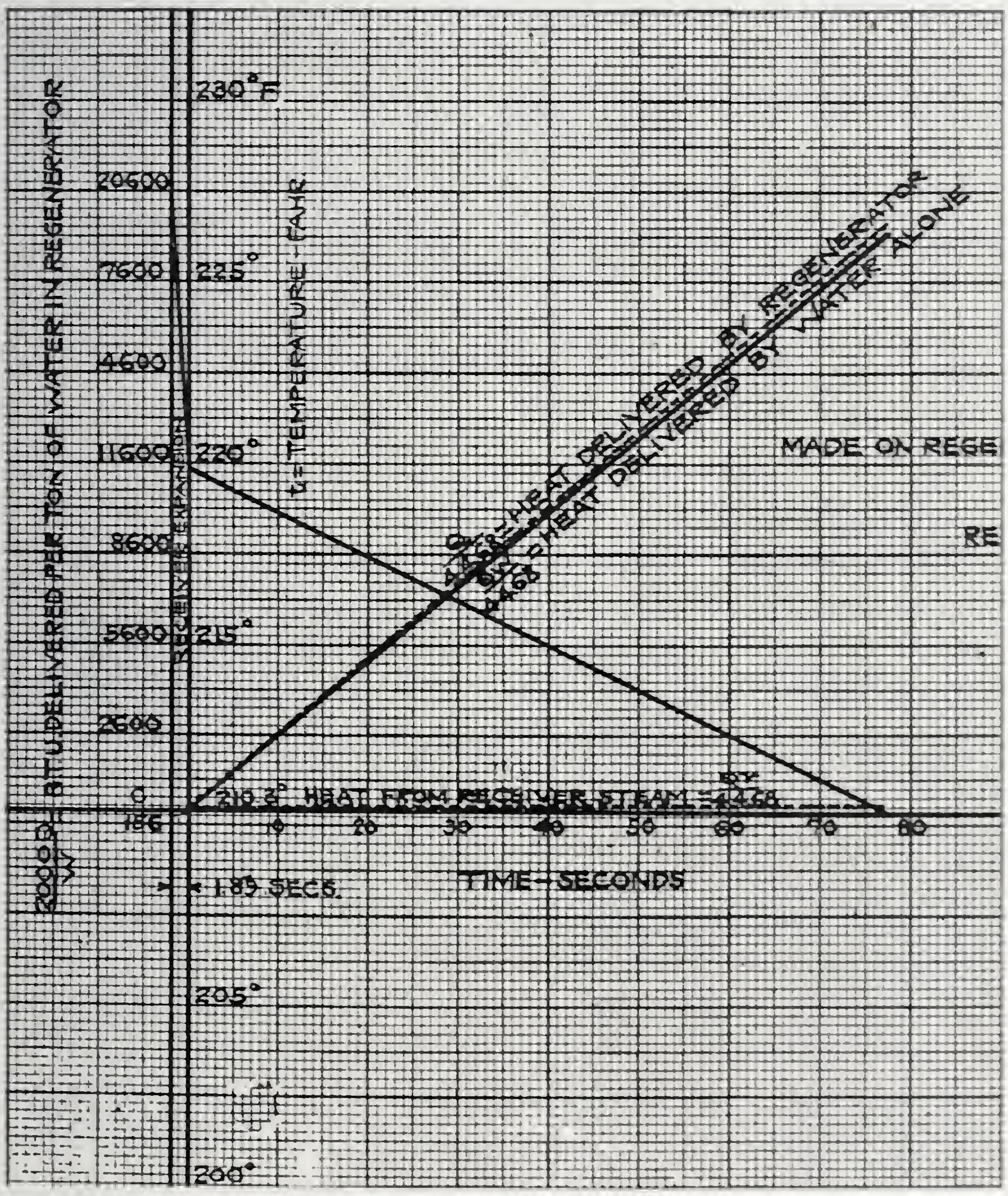
$T = 234.1$

$$t = 234.1 - \frac{23.8}{\epsilon^{0.17\,\theta}}$$

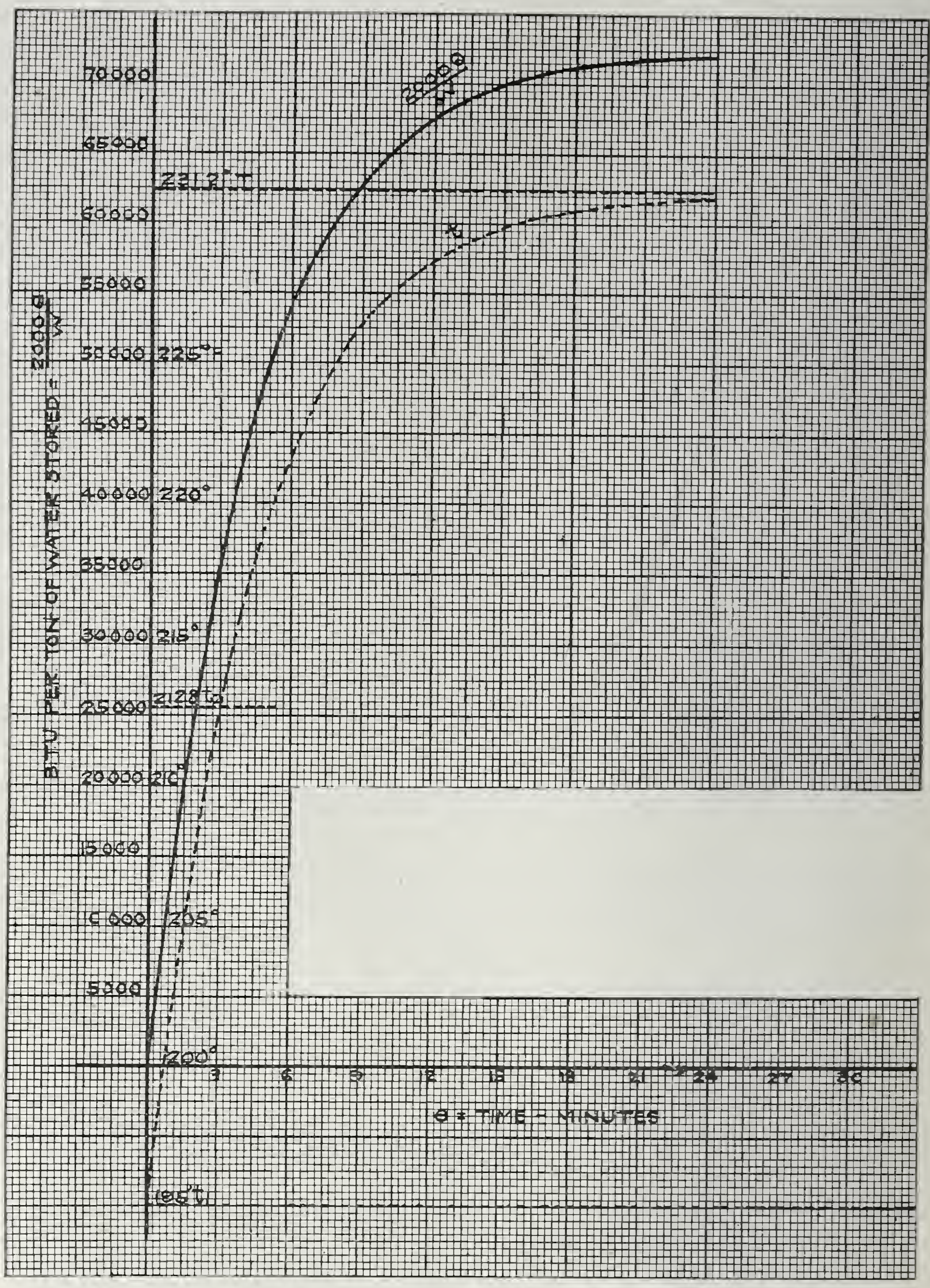
$$\frac{2000\,Q}{W} = 47\,600\left(1 - \frac{1}{\epsilon^{0.17\,\theta}}\right)$$

there are but two positions for this valve, closed and wide open, this valve no doubt would be objectionable if the generator was operating in parallel with other synchronous apparatus, but as we have but one unit the slight variations of speed are not objectionable.

Owing to an imperfection in the design of the pilot valve which operated the water mixing valve, it would find a position of admission and exhaust that would give to the piston of the operating cylinder a violent reciprocating motion which would break the valve stem and sometimes cause the valve to seat hard enough to break the body of it. A change in the design of the



Test No. 5. Regenerative Period.
Regenerator No. 2 at Turbine Station.



Test No. 6. Accumulative Period.
Regenerator No. 2 at Turbine Station.

$\theta = \quad 3.0$

$\Delta = \quad 0.226$

$t_1 = 195.0$

$t_2 = 212.8$

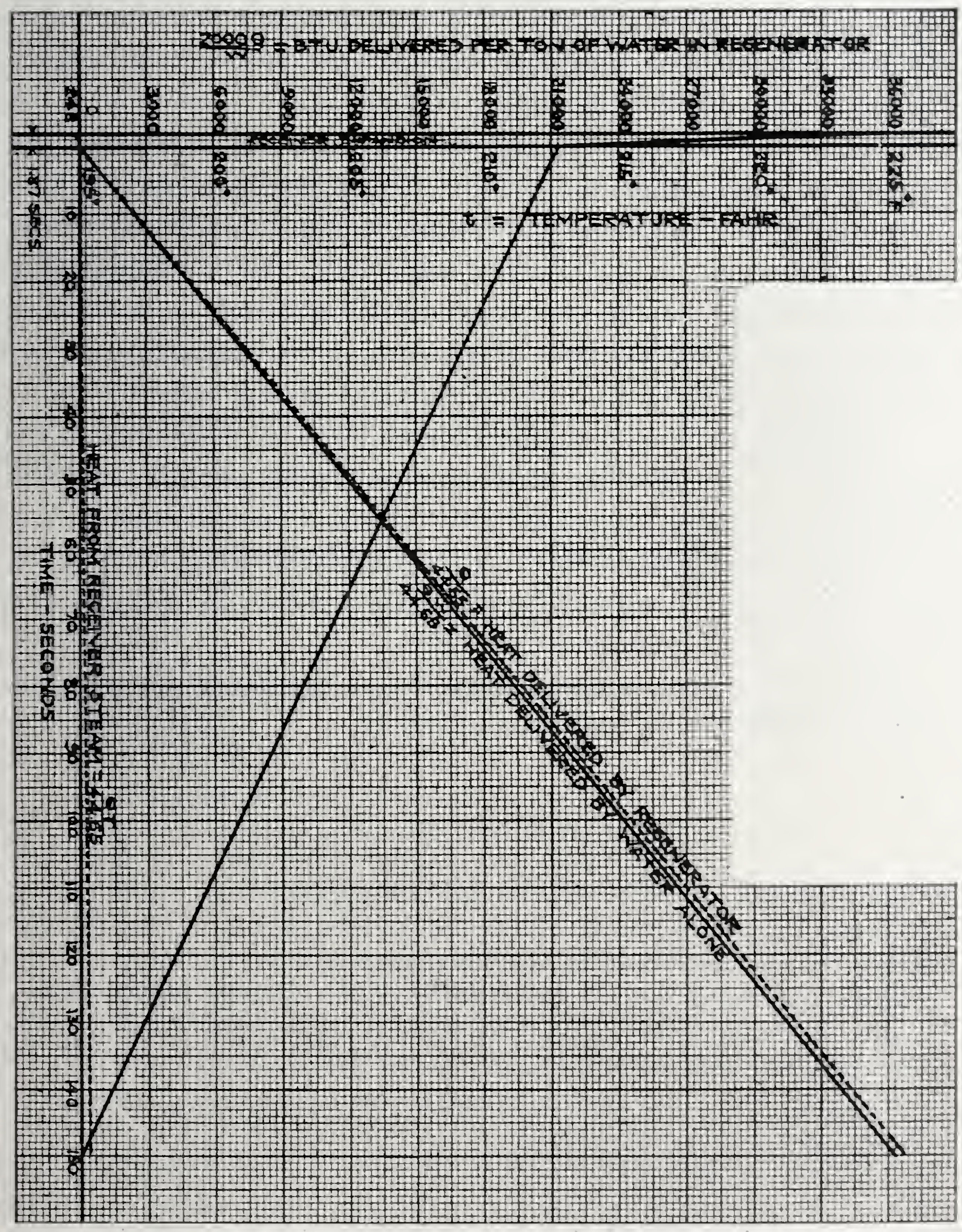
$T = 231.2$

$$t = 231.2 - \frac{36.2}{\epsilon^{0.226\,\theta}}$$

$$\frac{2000\ Q}{W} = 72\ 400\ \left(1 - \frac{1}{\epsilon^{0.226\ \theta}}\right)$$

piston and ports was made which eliminated this trouble.

In the lower chamber directly in the path of the incoming steam there is a vane which operates a pilot valve through levers. This vane due to improper operation of the pilot valve would be subjected to undue strains from the impacts of the incoming steam. After the pilot valve had been made to operate satisfactorily no more trouble was experienced from these vanes,



Test No. 6. Regenerative Period.
Regenerator No. 2 at Turbine Station.

which in the meantime had been changed from 16 gauge sheet to ⅛ in. plate.

Trouble was experienced with the seat getting loose and coming off the gate valve on the water connection between the upper and lower chambers. This seat was screwed on and would get loose in the threads. To overcome this trouble the seat was shrunk on, which eliminated the trouble from this source. While this is strictly valve trouble, it is mentioned in order to point out that a valve that would be satisfactory in ordinary service will not stand up in this service.

There is a water feed box in the upper chamber for the purpose of circulating the water by causing it to flow to the end opposite the injection end before it can be admitted to the lower chamber to be mixed with the steam. It was found that the water would be set in motion with sufficient force to tear this box loose from its fastenings, and it was necessary to securely fasten it to withstand the surging of the water.

The deposits of oil on the turbine blading, show that there should be a more effective method of removing the oil from the exhaust steam before it enters the turbine. A skimmer is now used which would probably be all right if the water was quiet, but as the water is always surging when steam is entering the regenerator, it is practically useless.

Since the above troubles have been eliminated the regenerators are giving complete satisfaction.

APPENDIX

TABLES, DIAGRAMS AND FORMULAE

Table No. 1: Steam to auxiliaries includes, for all tests, the circulating water pump and dry vacuum pump.

The circulating water pump being direct current motor driven, the steam consumption was figured from the power consumed by the motor, plus the conversion losses to the turbine.

Table No. 2: Shows the summary of tests made to determine the accumulative characteristics:

Estimate of the value of H^1: This is defined as the heat expenditure at a prime mover to accomplish the movement of w pounds of water per minute. This has purposely been left out of this paper, as it is not clear how this quantity should be determined.

Table No. 3: Shows the summary of tests made to determine the regenerative characteristics.

ENGINE DATA

Engines	*Blooming Mill*	*Slabbing Mill Horizontal*	*Slabbing Mill Vertical*
Type	Twin Simple	Twin Simple	Twin Simple
R. P. M.	100	100	100
Number		Two	Two
Bore	50 In.	46 In.	36 In.
Stroke	60 In.	60 In.	48 In.
Piston Rod Diam.	13½ In.	8 In.	6½ In.
Clearance in percent of piston displacement			
Head End	13	14	14
Crank End	17	14	14
Horse Power constant for 1 lb. m. e. p. and 1. r. p. m. $\frac{LA}{33000}$	0.5514	0.5200	0.2426

FORMULAE AND CONSTANTS

TURBO-GENERATOR TESTS

Table No. 1

X = Quality of steam to turbine.

$$= \frac{H - h - c\ (T_a - t_a)}{L}$$

$1 - X$ = Moisture in steam to turbine.
H = Total heat of steam in main pipe.
L = Latent heat of steam in main pipe.
h = Total heat due to the pressure in the discharge side of the calorimeter.
c = Specific heat of super-heated steam.
T_a = Temperature of the throttled and super-heated steam in the calorimeter.
t_a = Temperature due to the pressure in the calorimeter.

HEAT AVAILABLE IN A POUND OF STEAM

H_1 = Heat available in a pound of steam as supplied to turbine.

$$= L_a X + q\ (1 - X) - (t_a - 32)$$

L_a = Total heat of steam as supplied to turbine.
X = Quality of steam.

q = Heat of liquid corresponding to L_a.
t_a = Temperature of hot well.

HEAT SUPPLIED TO TURBINE

Q_a = Total heat supplied to turbine.
$= W\,(T_b - T_c) + Q_b + Q_c + Q_d$
W = Pounds of condensing water.
T_b = Temperature of hot well.
T_c = Temperature of cooling water.
$Q_b + Q_c$ = Radiation losses from turbine and piping.
Q_d = Heat equivalent of work at turbine shaft.

HEAT UNITS SUPPLIED TO TURBINE AND AUXILIARIES

Q_e = Heat units to turbine and auxiliaries.
$= Q_a + Q_f + Q_g$
Q_f = Heat units consumed by circulating pump.
Q_g = Heat units consumed by air pump.

STEAM SUPPLIED TO TURBINE

S = Pounds of steam supplied to turbine.
$= \dfrac{Q_a}{H_1}$.

STEAM SUPPLIED TO TURBINE AND AUXILIARIES

S_a = Pounds of steam to turbine and auxiliaries.
$= \dfrac{Q_e}{H_1}$

THERMAL EFFICIENCY RATIO

E = Thermal efficiency ratio per brake horse power.
$= \dfrac{2545}{S_f\ H_1}$
S_f = Pounds of steam per brake horse power per hour.

RATIO OF ECONOMY

E_1 = Rates of economy of turbine to that of an ideal turbine working on the Rankine cycle.
$= \dfrac{T_d - T_e}{T_d}$
T_d = Absolute temperatures of steam entering turbine.
T_e = Absolute temperature in the condenser.

REGENERATOR TESTS (ACCUMULATIVE PERIOD)

Table No. 2

W = Weight of heat absorbing water, pounds.
θ = Time in minutes during which heat is applied to the absorbing water.
T = Temperature of steam entering the regenerator, deg. Fahr.

TABLE NO. 1—DATA AND RESULTS OF TURBO-GENERATOR TESTS

1	Date		Jan. 19, 1913	Jan. 19, 1913	Jan 19, 1913	Jan. 19, 1913	Jan. 22, 1913	Jan 24, 1913	Feb 2, 1913	Feb. 2, 1913	Feb. 2, 1913
2	Duration	hr.	1 Hour	1 Hour	1 Hour	1 Hour	1 Hour	2 Hours	1 Hour	1 Hour	1 Hour
3	Steam Pipe Pressure Near Throttle, by Gage	lb.	1.48	1.88	1.88	1.96	1 73	3.33	2.73	5.56	3.00
4	Barometric Pressure of Atmosphere in Inches of Mercury	in	29.65	29.64	29.59	29.54	29.77	29.41	29.90	29.78	29.77
5	Vacuum in Condenser in Inches of Mercury	in.	28.11	28.19	28 20	28.02	28.25	27.68	28.25	27.93	28.43
6	Vacuum in Condenser—Corresponding Absolute Pressure	lb.	0.756	0.712	0.682	0.746	0.746	0.849	0.810	0.908	0.658
7	Temperature of Injection or Circulating Water Entering Condenser	deg.	43.50	43.50	43.50	43.50	41.00	44.00	34.00	34.00	34.00
8	Temperature of Injection or Circulating Water Leaving Condenser	deg	61.50	65.00	72.70	78.10	75 30	74.80	66.50	58.00	58.90
9	Moisture in Steam	Percent	1.68	1.62	1.69	1.58	1.63	1.70	1.64	1.66	1.60
	Hourly Quantities										
10	Total Dry Steam consumed per hour	lb.	49 529.20	60 797.70	79 170.30	102 523.90	111 819.70	109 683.00	102 243.10	112 244.10	74 517.10
11	Net Dry Steam consumed per hour	lb.	49 529.20	60 797.70	79 170 30	102 523.90	111 819.70	109 683.00	102 243.10	112 244.10	74 517 10
12	Dry Steam consumed per hour by Turbine	lb.	43 553.80	56 648.80	75 123.90	98 495 70	107 810.20	105 482.10	98 302.50	108 437.60	70 679.30
13	Dry Steam consumed per hour by Auxiliaries	lb.	5 975.40	4 148.90	4 046.40	4 028.20	4 009.50	4 200.90	3 940.60	3 806.50	3 837.80
14	Injection or Circulating Water Supplied Condenser per Hour	cu. ft.	40 691.00	42 199.20	40 594.00	44 680.00	49 820 40	54 393.40	47 685.60	71 820.00	45 183.60
	Heat Data										
15	Heat Units per lb. of Dry Steam, based on Temp. of Steam (Line 3)	B. t. u.	1 105.40	1 101.90	1 094.20	1 088.80	1 092.60	1 094.80	1 102.40	1 113.90	1 110.50
16	Total Heat Units consumed per hr. for all purposes	B. t. u.	54 749 577	66 992 986	86 628 142	111 628 022	122 174 204	120 080 948	112 712 793	125 028 702	82 751 239
17	Heat Units consumed per hr. by Turbine and Auxiliaries	B. t. u.	54 749 577	66 992 986	86 628 142	111 628 022	122 174 204	120 080 948	112 712 793	125 028 702	82 751 239
18	Heat Units consumed per hr. by Turbine alone	B. t. u.	48 144 370	62 421 313	82 200 571	107 242 118	117 793 425	115 481 803	108 368 676	120 788 642	78 489 363
19	Heat Units consumed per hr. by Auxiliaries	B t. u.	6 605 207	4 571 673	4 427 571	4 385 904	4 380 779	4 599 145	4 344 117	4 240 060	4 261 876
	Electric Data										
20	Average Volts Each Phase	Volts	6 600	6 600	6 600	6 600	6 600	6 600	6 678	6 570	6 660
21	Average Amperes Each Phase	Amperes	66.60	153.50	196.80	263.00	272.00	265.00	284.00	327.60	185.00
22	Total Kilowatt Output	k. w.	682.21	1 486.98	2 178.00	2 893.77	3 021.48	2 960.10	3 152.16	3 630.33	2 194 83
23	Power Factor		89 20	97.50	96.80	96.30	97.30	97.80	96.10	97.50	97.60
24	Output consumed by Exciter	k. w.	15.96	16.19	17.21	21.26	19.96	20.65	24.79	25.07	19.18
25	Net Kilowatt Output	k. w.	666.25	1 470.79	2 160.79	2 872.51	3 001 52	2 939.45	3 127.37	3 605.26	2 175.65
	Speed										
26	Revolutions per Minute	r. p. m.	1 500	1 500	1 500	1 476	1 458	1 465	1 457	1 458	1 494
27	Variation of Speed between no Load and Full Load	Percent	0.00	0.00	0.00	1.60	2.80	2.30	2.90	2.80	0.40
	Power										
28	Brake Horsepower	Br. b. p.	1 168 85	2 256.13	3 207.91	4 198.79	4 355.10	4 270.40	4 546.38	5 162.69	3 224 40
29	Electrical Horsepower	h. p.	914.49	1 993.27	2 919.57	3 879.05	4 050.24	3 967.96	4 225.42	4 866.39	2 942.13
	Economy Results										
30	Heat Units consumed by Turbine and Auxiliaries per brake h. p. hr.	B. t. u.	46 841	29 694	27 004	26 586	28 053	28 119	24 793	24 218	25 664
31	Dry Steam consumed per brake h. p. hr. by Turbine and Auxiliaries	lb.	42.37	26.95	24.68	24 42	25.67	25.69	22.49	21.74	23 11
32	Dry Steam consumed per brake h. p. hr. by Turbine alone	lb.	37.26	25.11	23.42	23.46	24.75	24.70	21.62	21.00	21.92
33	Dry Steam consumed per brake h. p. hr. by Auxiliaries	lb.	5.11	1.84	1.26	0.96	0.92	0.98	0.87	0.74	1.19
34	Dry Steam consumed per k. w. hr. by Turbine and Auxiliaries	lb.	74.34	41.34	36.64	35.69	37.25	37.31	32.69	31.13	34.25
35	Dry Steam consumed per k. w. hr. by Turbine alone	lb.	65.37	38.52	34.77	34.29	35.92	35.88	31.43	30.08	32.48
36	Dry Steam consumed per k. w. hr. by Auxiliaries	lb.	8.97	2.82	1.87	1.40	1.33	1.43	1.26	1.05	1.77
	Efficiency Results										
37	Thermal Efficiency Ratio per Brake Horsepower	Percent	0.0618	0.092	0.0993	0.0996	0.0941	0.0941	0.1068	0 0188	0 1045
38	Ratio of Economy of Turbine to that of an Ideal Turbine Working with the Rankine Cycle		0.2288	0.2257	0.2143	0.2063	0.2105	0.2165	0.2271	0.2474	0.2389
	Work Done Per Heat Unit										
39	Foot pounds of Net Work per B. t. u. consumed by Turbine and Auxiliaries (1,980,000 ÷ Line 30)	ft. lb.	42.10	66.70	73.30	74.50	70.60	70.40	79.90	81.70	77.20

$t_1 =$ Initial temperature of absorbing water, deg. Fahr.
$t_2 =$ Final temperature of absorbing water, deg. Fahr.
$t =$ Intermediate temperature of absorbing water, deg. Fahr.
$Q =$ Heat absorbed, B. t. u.

$$\Delta = \frac{w}{W}$$

$w =$ Weight of water circulated per minute, pounds.
$Q = W\ (t_2 - t_1)$

Δ is figured from the formula $Q = W\ (T - t_1) \left(1 - \frac{1}{\epsilon^{\Delta\theta}}\right)$

$$\Delta = \frac{log_{10} \left(\frac{1}{1 - \frac{Q}{W\ (T - t_1)}} \right)}{\theta\ log_{10}\epsilon}$$

$\epsilon = 2.71828 =$ Base of Naperian Logarithms.

$$t = T\ \frac{T - t_1}{\epsilon^{\Delta\theta}}$$

$$\frac{2000\ Q}{W} = 2000\ (T - t_1)\ \left(1 - \epsilon^{-\Delta\theta}\right)$$

REGENERATOR TESTS (REGENERATIVE PERIOD)

Table No. 3

$V =$ Volume of receiver spaces, cubic feet.
$W =$ Weight of heat absorbing water, pounds.
$m =$ Pounds of steam per minute from the regenerator.
$t_3 =$ Temperature of steam entering the regenerator, deg. Fahr.
$t_2 =$ Final temperature of absorbing water, deg. Fahr.
$t_1 =$ Initial temperature of absorbing water, deg. Fahr.
$S_3 =$ Specific volume of steam at a temperature t_3
$S_1 =$ Specific volume of steam at a temperature t_1
$H_3 =$ Total heat of steam at a temperature t_3
$H_2 =$ Total heat of steam at a temperature t_2
$H_1 =$ Total heat of steam at a temperature t_1
$\theta\ (t_3$ to $t_2) =$ Time in seconds for receiver expansion from t_3 to t_2
$\theta\ (t_3$ to $t_1) =$ Time in seconds for regenerator expansion complete from t_3 to t_1

$$\theta\ (t_3 \text{ to } t_2) = 60\ \frac{V}{m} \left[0.0389\ (t_3 - t_2) - 270\ log_{10} \frac{H_3}{H_2} \right]$$

$$\theta\ (t_3 \text{ to } t_1) = \frac{60}{m} \left[\frac{W - 44\ V}{0.3745}\ log_\epsilon \frac{H_2}{H_1} + 0.0389\ V\ (t_2 - t_1) \right]$$

$$Q \text{ (actual heat storage)} = W\,(t_2 - t_1) + V\left(\frac{H_3}{S_3} - \frac{H_1}{S_1}\right)$$

$$Q \text{ (theoretical heat capacity)} = Q\,(t_3 - t_1) + V\left(\frac{H_3}{S_3} - \frac{H_1}{S_1}\right)$$

$$\text{Efficiency} = \frac{Q \text{ (actual heat storage)}}{Q \text{ (theoretical heat capacity)}}$$

TABLE NO. 2—SUMMARY OF TESTS

MADE ON REGENERATOR NO. 2—AT TURBINE STATION

ACCUMULATIVE PERIOD

Test No.	Tank	W LB.	θ MIN.	T DEG. F.	t_1 DEG. F.	t_2 DEG. F.	Q B. t. u.	Δ	w LB.
1	2	93 909	4	229.30	205.00	216.00	1 032 999	0.151	14 180
2	2	88 222	4	231.20	206.50	216.20	855 753	0.125	11 028
3	2	88 178	3	235.50	206.30	219.30	1 146 314	0.197	17 371
4	2	94 374	3	232.10	195.20	214.20	1 793 076	0.241	22 744
5	2	89 363	3	234.10	210.30	219.80	848 945	0.170	15 174
6	2	89 292	3	231.20	195.00	212.80	1 589 398	0.226	20 180

TABLE NO. 3—SUMMARY OF TESTS

MADE ON REGENERATOR NO. 2 AT TURBINE STATION

REGENERATIVE PERIOD

Test No.	Tank No.	V cu. ft.	W lb.	m lb.	t_3 deg. F	t_2 deg. F	t_1 deg. F	θ (t_3 to t_2) sec.	θ sec.	Q Actual Heat Storage	Q Theoretical Heat Capacity	Efficiency %
1	2	896	93 909	567	222.3	216.0	205.0	1.00	88.2	1 045 800	1 637 280	63.8
2	2	991	88 200	567	225.1	216.2	206.5	1.85	77.3	871 257	1 656 237	52.6
3	2	991	88 178	567	227.1	219.3	206.3	2.08	101.8	1 164 132	1 851 920	62.8
4	2	893	94 374	567	225.0	214.2	195.2	3.21	162.8	1 814 245	2 833 384	64.0
5	2	970	89 363	567	227.2	219.8	210.3	1.89	77.4	863 653	1 524 939	56.6
6	2	979	89 292	567	225.3	212.8	195.0	1.87	150.0	1 612 865	2 729 013	59.1

$$\theta = \text{Time for Receiver Expansion} = \frac{V}{M}\left(0.0389\ (t_3 - t_2) - 270\ \log_{10} \frac{H_2}{H_3}\right)$$

$$\theta = \text{Time for Regenerator Expansion} = \frac{1}{M}\left(\frac{W - 44\ V}{0.3745} \log_\epsilon \frac{H_2}{H_1} + 0.0389\ V\ (t_2 - t_1)\right)$$

$$Q = \frac{V}{\text{Tons Water}} = (t_3 - t_2)\left\{0.00729\ (t_3 + t_2) - 2.2877\right\}$$

$$\frac{Q_w}{\text{Tons Water}} = w\ \frac{t_2 - t_1}{\text{Tons Water}}$$

$$\frac{Q}{\text{Tons Water}} = \frac{Q_w}{\text{Tons Water}} + \frac{Q_r}{\text{Tons Water}}$$

NOTES ON SPECIFICATIONS FOR REGENERATORS

By O. P. Hood*

The following notes are offered as a result of some experience in testing a regenerator installation in the effort to discover whether a contract specifying certain capacity and performance had been fulfilled. It was desired by the buyer that the regenerator usefully employ the exhaust steam from a large hoisting engine having two cylinders 52 in. by 84 in., the engine running non-condensing.

There was about 900 to 1000 pounds of dry exhaust steam available from each full hoisting period of about two minutes with an interval of about five minutes between hoists. The hoisting was in balance from depths of about 5000 feet. The rope, skip and loads were heavy and the torque requirements varied between wide limits, so that during the first part of the accelerating period steam was used non-expansively the full length of the stroke, while during the latter part of the hoist the cut off was exceedingly short and expansion continued below atmospheric pressure. The heavy exhaust of the first period was a very evident waste, so that a proposition that would engage to retain this steam and return a useful product was looked upon with favor. The matter was first taken up in 1905, when the regenerator was a new thing in this country. Foreign experience had been confined to much smaller engines serving shallower mines. At that time the agreement the buyer was asked to sign contained the following statement:

"The capacity of the regenerator plant shall be sufficient to handle the maximum hourly rate of delivery (of exhaust steam) to the best practical advantage."

The buyer decided that such a statement of capacity was entirely too indefinite to insure a device that would use a fair proportion of his waste product and insure no interference with the hoisting function. At this time there was great difficulty in getting into a contract a clear statement of just what such a device would do expressed in quantities which could be measured

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by test, and I believe there is still some difficulty in this regard. After some years of consideration an installation was finally made the contract containing the following statement: "The regenerator will be of sufficient size to operate a 300 k.w. turbine unit for a period of five minutes after the supply of steam is shut off." This was a fairly definite statement of capacity of output readily determined, but this was qualified by a further statement which was intended to cover the capacity of input as follows: "Provided the supply has been maintained for a sufficient time to provide as many heat units as the containing water will absorb at the operating pressure;" that is to say, whether the device was efficient in absorbing heat or not, the buyer was asked to supply steam until the absorption was complete. This was of course very indefinite and unsatisfactory, as it established no standard of rate of absorption whatever, but the state of the art apparently made no more satisfactory statement possible at that time. It was further stipulated that "An automatic release valve will be provided to allow a free escape of the steam when the pressure exceeds one pound above the present exhaust pressure." This latter statement was very important. It seemingly gave something definite to measure and limited the effect which the regenerator might have on the hoisting engine to an increased back pressure of one pound. We now know that this limit was probably lower than one had a right to expect, but this and the previous unsatisfactory provision go to show the lack of sufficiently definite information to make a contract safe for both buyer and seller. It is evidently to the advantage of the regenerator to have as wide a range of pressure as possible. There are many objections to running the pressure below the atmosphere on such a hoist. The lower regenerator pressure was therefore limited to approximately atmospheric pressure. The superior pressure allowed on the regenerator adds to the back pressure on the engines, and this addition increases their normal steam consumption. It is between these narrow limits of pressure that the regenerator must run. With increasing back pressure there comes a condition where the saving at the exhaust end of the operation is more than offset by the cost of the added steam needed by the main engines and the added auxiliaries.

At one period in the development of the installation referred to, which was changed or readjusted several times, the added amount of steam required by the plant could have been used directly in a plain slide valve engine belted to a generator and have returned as much current as was obtained from the turbo regenerator unit which was intended to save the whole exhaust. It is not sufficient to point out that steam is used in such a combination somewhat as in a compound condensing unit and that therefore economy must follow, for most regenerator plants are not of sufficient capacity to prevent the blowing to waste of a considerable quantity of exhaust steam on peak loads in each cycle. This portion of the steam is therefore used in a very uneconomical manner and lowers the general efficiency of the whole operation materially. This is one reason why some plants of this kind, although returning a product from exhaust steam, are unable to drop any boiler capacity as a result of the installation. From a comparison of continuous indicator cards for a full hoisting cycle under several conditions of back pressure the conclusion was reached that for this plant about three percent increase in steam was required for each added pound of back pressure on the engine, and as the regenerator was unable to retain all of the normal exhaust this increase would be fatal to ultimate economy unless the back pressure could be kept low or the capacity increased to hold all of the exhaust. The device as first installed increased the back pressure 8 or 10 lb. and required 25 to 30 percent increase in steam used by the plant.

In testing the plant to determine whether the agreements had been fulfilled it was necessary to measure the electrical output, to measure the time during which no exhaust steam came from the hoist, to record the succession of hoisting events, and to determine the added back pressure on the hoist. The electrical measurements presented no special problem. To record time simply by a stop watch and then to keep records by notes led immediately to differences of opinion and to different records as to the facts. There was no way of determining which record was right without a graphical record of events. A circular time chart recording pressures radially was considered unsatisfactory, as the time space record is too short and with a hoist the pressure

variations came too close together to give legible records. A satisfactory record was made on a lead faced roll of paper traveling about 1 1-3 inches per minute upon which minutes were marked by a clock mechanism. On this roll there were recorded atmospheric pressure, pressure in the regenerator, duration of opening of the relief valve on the regenerator, and duration of admission of live steam to the turbine. On this same paper were recorded all other observations such as load, vacuum, steam pressure on the hoist, character of hoisting and other remarks. This gave the time of each observation and its relation to the other rapidly changing variables, which was found to be very useful. I believe some such graphical record absolutely necessary in a test of this kind.

The apparently simple condition of the contract that there should be "a free escape of the steam when the pressure exceeds one pound above the present exhaust pressure" proved to be far from simple in determination. The designers of the regenerator had first to determine what the old back pressure was in order to discover the range of pressure they could work with and therefore the size of the device. There may be a very honest difference of opinion as to the meaning of the phrase "back pressure" and also several very poor ways of determining what it is. One way would be to ask somebody and thus put the responsibility on someone else. They may guess at it. It is surprising how often this is done. Another way would be to connect a steam gage to the exhaust line with a small pipe of greater or less vertical and horizontal extension so that with a violent exhaust the inertia of a small pipe full of water would hammer the gage and at slow running with an initial exhaust pressure below the atmosphere the inertia and the weight of the column of water would hang on the gage. By a suitable combination of these elements one can get any back pressure desired and all of them wrong. Third, one may try to take the back pressure from continuous cards using a 60 lb. spring. This is equally futile, as the spring is too stiff to show the small pressures and the exhaust lines on closed continuous diagrams are usually too confused to interpret. The exhaust pressure line may be different for each stroke of a hoisting engine—which

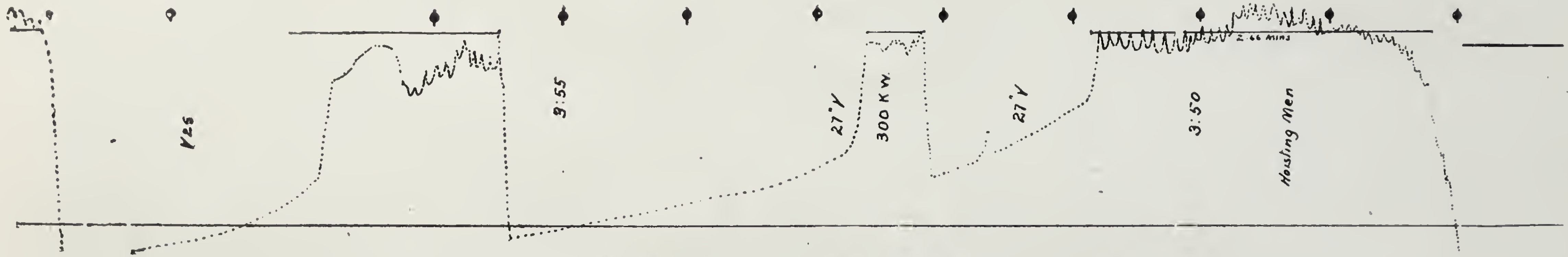


Chart No. 4. Pressure—Time Diagram showing Pressures in Regenerator before remodeling. Scale of Spring : 1 inch = 4 lb.

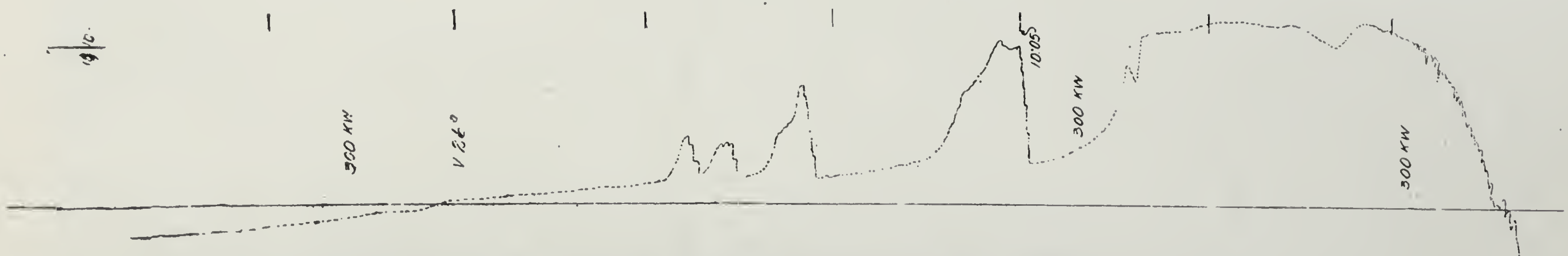
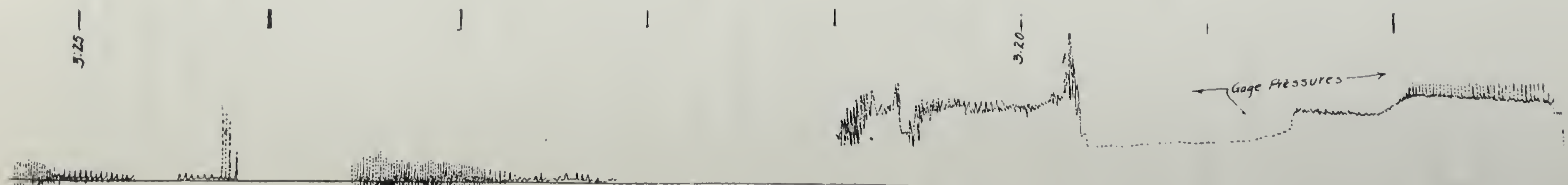


Chart No. 5. Pressure—Time Diagram showing Pressures in Regenerator after remodeling. Scale of Spring: 1 inch = 4 lb.



10 lb. Spring. Free Exhaust.

Chart No. 6. Steam Pressures in the Exhaust Line near the steam cylinders with and without the Regenerator.

10 lb. Spring. Exhaust Regenerator. Load 100 k.w.

of these strokes then shall be taken to represent the "back pressure" referred to in a contract? The average back pressure for a stroke during the accelerating period may be a pound or two greater than for a stroke during the retarding period, and this pound or two is a considerable proportion of the full range of pressure allowed in a regenerator.

The most satisfactory method of determining the back pressure would be to take continuous indicator diagrams of the open type using a light spring arranged with a positive stop so that pressures beyond the range of the spring would not injure it. The average back pressure for each stroke of the cycle could then be plotted as an ordinate with the number of the stroke as a base thus giving a curve representing the many back pressures through the cycle. Such curves obtained under different conditions would be comparable and the pressure range allowed between them could be a definite matter of contract. While this procedure is desirable such indicators are by no means common. A reasonably good substitute may be found in a diagram traced on a paper having a slow uniform motion at right angles to the movement of an ordinary indicator pencil, the indicator having a light spring and mounted with a very short connection on the exhaust pipe as close to the engine as possible.

In such a diagram the instantaneous exhaust pressures may throw the pencil too high but where the pencil dwells the longest a dark band is traced which corresponds fairly closely to the mean back pressure. During the latter part of the hoisting cycle the exhaust pressure at release is below the atmospheric pressure causing an inrush of air into the exhaust pipe which air must later be reversed and pushed out of the cylinder and exhaust pipe. This lowers the average exhaust pressure of the whole cycle very materially. In the large engines referred to the average back pressure with free exhaust was found to be something less than one pound, although six or eight pounds had been assumed as the back pressure.

It seems to me desirable that in specifications for such installations the method of determining the back pressure on the engines should be a part of the contract, as well as the

allowed addition of pressure imposed by the regenerator.

It is also desirable, when applied to the exhaust of a hoist or similar engine, that the regenerator pressure be automatically adjusted, according to the load on the turbine, if this is a variable. It may frequently happen that the load on the turbine is light, not requiring the full capacity of the regenerator, at a time when a large amount of exhaust steam is available. It is evidently uneconomical if this exhaust must be made under conditions of increased back pressure which is beyond the requirements and the capacity of the regenerator.

Although great savings can be made by the use of regenerators attached to hoisting engines, it takes only small additions of back pressure in connection with regenerators of insufficient capacity to change an apparent saving at the exhaust into an actual loss at the coal pile, and many plants are so interconnected with other engines as to make the facts very difficult to discover.

EXPERIMENTS WITH A SMALL STEAM REGENERATOR

By C. L. W. Trinks*

In Mr. Gasche's memorable paper on Steam Accumulators an absorption coefficient K for induced current regenerators is used, and the desirability of making tests for the determination of that coefficient is emphasized. Since I had some doubts on the coefficients used in Mr. Gasche's illustrative case, I set out to investigate an induced current regenerator.

While I have no commercial regenerator at my disposal, I had an experimental one made of 20 in. pipe. The inside parts were made of galvanized iron. A relief valve was provided and a combination of a spraying tank and a steam separator was used to insure commercially dry steam. This apparatus is at the present reading still set up in the Mechanical Engineering Laboratory of the Carnegie Institute of Technology. A test showed that even with moderate amounts of steam flowing

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a large percentage of the steam passed through the water without being absorbed, although there was a considerable temperature difference between the entering steam and the water. A study of the situation convinced me that tests on this regenerator would be of no more use to engineers than the test on any other regenerator and that it would furnish only the absorbing characteristics of this particular piece of apparatus without allowing inferences and conclusions of a more general nature.

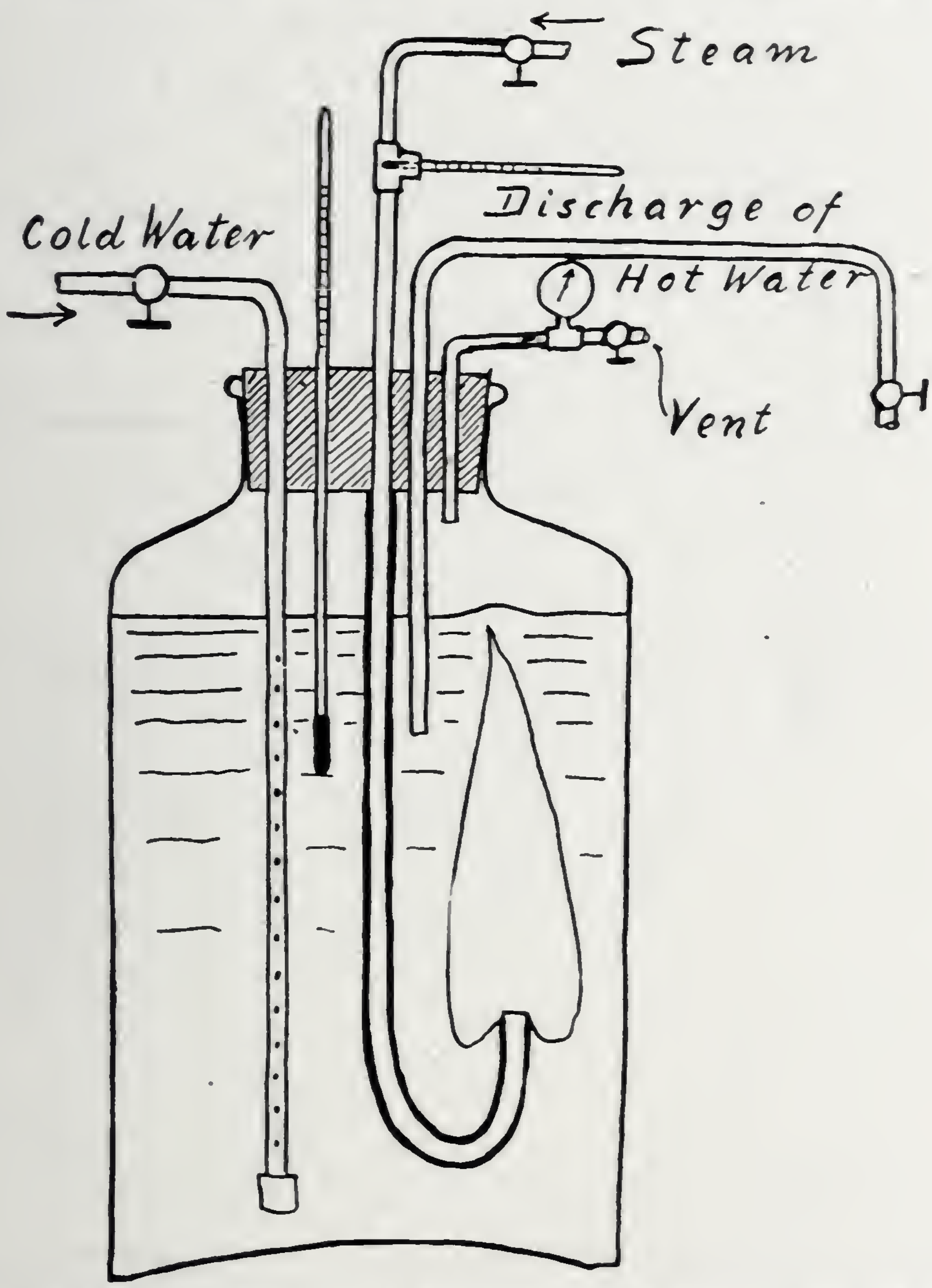

Fig. 13. Apparatus for Total Absorption of Single Jet of Steam.

For this reason I decided to change the method of attack and to approach the problem by the study of the elements, keeping as many factors constant as possible and varying only one at a time. While in the ordinary regenerator temperatures and pressures are continually changing, I kept temperature,

pressure and water level constant by the addition of cold water and by the discharge of hot water. In order to see what was going on I used glass containers. See Fig. 13. Steam was added in such quantities that all of it was just absorbed at the surface of the water. The slightest increase in the quantity of steam caused the steam jets to become short and the temperature to fall. This condition represents the limit of total steam ab-

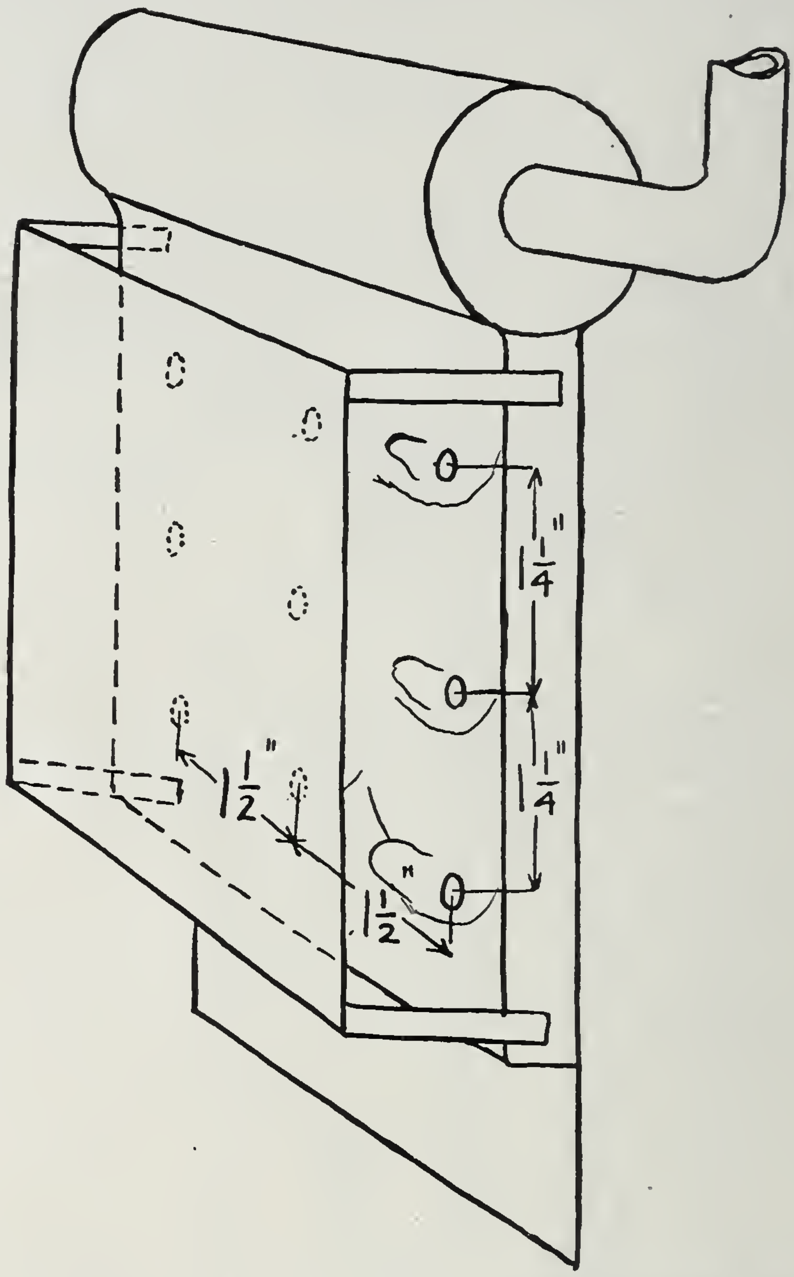

Fig. 14. Element of an Experimental Rateau type Regenerator.

sorption for the given discharge orifice, temperature difference, and depth of immersion. The equilibrium is unstable and needs constant attention and frequent regulation.

At first I used a single jet of steam, the shape of which was somewhat of a surprise to all who witnessed the test. We expected to see bubbles rise through the water, but, instead, the jet expanded to at least four times the size of the pipe opening

and looked very much like an unsteady flickering flame, the top of which was darting hither and thither. From this simple experiment the rate at which steam can be absorbed with varying temperature differences and with varying depth of immersion was found for a single opening directed upwardly. The rate at which steam can be absorbed was found to be directly proportional to the temperature difference and to the depth of immersion. The unexpected spreading of the steam jet was probably due to the resistance which it found against the water in trying to rise.

A small box was then used resembling a section of a regenerator element. It was discovered that the steam coming out of the lateral holes spread to such an extent that the steam jets interfered with each other which fact will be dealt with in detail further on. It was also discovered that the kinetic energy of the downward flow of the steam caused an excessively large amount to be discharged at the bottom opening. Hence a new and larger section was made; it was designed in a manner similar to the element used by Mr. Rateau. The illustration Fig. 14 shows the design of this element. At this stage the large wide mouthed bottles which had been used up to this time had to be abandoned on account of insufficient size and large jars of storage battery cells were substituted. These proved to be very troublesome because they invariably cracked after one test. Finally a large fish bowl was substituted which stood the change of pressure and temperature remarkably well.

From Fig. 14 it will be noticed that this regenerator element was provided with a baffle so as to produce induced circulation. The left hand part of Fig. 15 shows approximately the appearance of the steam jets. It will at once be seen that the shape of steam jet as indicated in the paper by Mr. Gasche and in the catalogue of the Rateau regenerator company is purely imaginary. Steam does not rise in a series of bubbles, but spreads laterally immediately after leaving the holes and is forced flat against the walls of the steam box, thus offering practically a vertical wall of contact between the steam and water. The results of these tests are given in the curve, Fig. 16. It will be seen that complete steam absorption with small temper-

ature differences necessitates a very slow rate of flow of steam and discharge through the upper row of holes only. If complete absorption of steam and discharge through several rows of holes is wanted the temperature difference between the steam and water must be quite excessive. With permissible temperature difference and for complete absorption of steam a horizontal length of absorbing surface of about three miles will be necessary for an ordinary 55 by 60 reversing engine doing

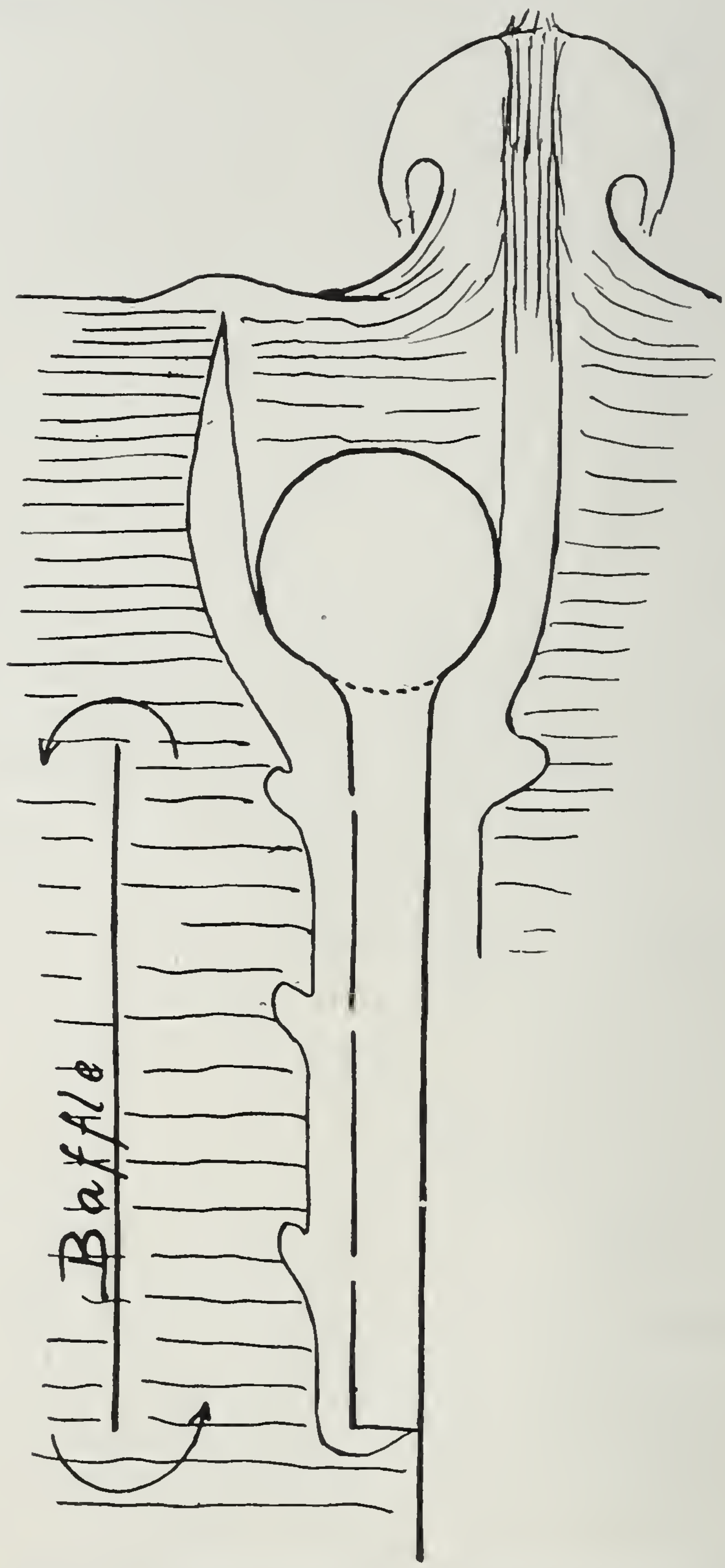

Fig. 15. Appearance of Steam Jets in Experimental Regenerator.

medium, heavy work at 60 r. p. m. This figure is based on 15 deg Fahr. temperature difference and a four inch depth of immersion. If three regenerators were used, each with four absorbing surfaces, and if the depth of immersion be increased to 10 in., then the length of the regenerator could be reduced to 500 feet.

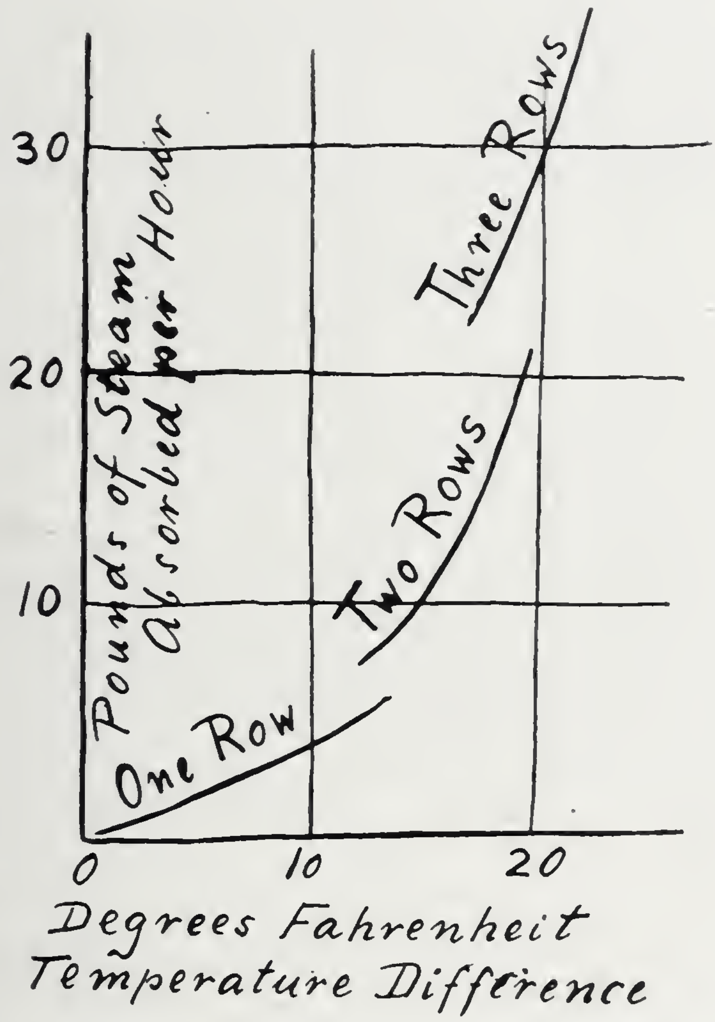

Fig. 16. Rate of Total Absorption under varying conditions.

From this short calculation it is at once evident that regenerators as designed now cannot absorb all of the steam which comes from a reversing mill engine unless the temperature difference is excessive. For total absorption, regenerators would have to be redesigned in the shape of multiple flat boxes with considerable less depth of immersion and only one row of holes.

While such a design of regenerator would be theoretically perfect, it is probably commercially impossible on account of the cost. We must, therefore, make up our minds that varying fractions of the steam sent from the engine must be discharged into the space above the water, either raising the pressure, going to the turbine, or escaping through a relief valve.

For the purpose of testing steam absorption under conditions of heavier steam flow, arrangements were made to work with an open outlet and to measure the escaping steam by absorption in cold water. This however, proved to be impractical, because the escaping steam was full of water. Hence the total amount of steam flowing was determined after each test by increasing the water flow, leaving the steam flow constant and making a heat balance with total absorption.

It was found that with a comparatively small quantity of steam passing off unabsorbed, the rate of steam absorption could be vastly increased, namely from five to ten times, depending upon the rate of flow. A faster flow lifts the water higher, so that first the length of water and steam contact is increased, and second the water falls back through the steam space, absorbing more heat, (see right hand portion of Fig. 15), furthermore the mixture of steam and water appears to be more intimate in the "boiling wave."

There is then no well defined limit to the steam absorption. With increased flow more is absorbed, but the water is lifted so high and the steam passing through entrains so much water that the operation of the turbine finally becomes dangerous.

If we return to the original example of absorbing the exhaust of a 55 by 60 reversing engine and figure with ten times the absorption allowed in the limiting condition, the length of the regenerator would be reduced to 50 ft. However, the steam coming from the regenerator will now carry a considerable amount of moisture.

I am convinced that by rebuilding our test apparatus even more valuable results could be obtained, but such test should really be left to the builders of regenerators. The tests up to this point have taken a great deal of work and time on the part of myself, of Mr. Raisig and of the laboratory mechanic of Carnegie Institute of Technology.

To sum up the results obtained: Steam absorption is proportional to temperature difference and to depth of immersion. No well defined bubbles are found in the Rateau regenerator, but a solid sheet of steam. If this sheet is to be all absorbed without any of it breaking through the surface, the size of re-

generator is commercially impossible. By letting some of the steam pass through unabsorbed, the rate of absorption can be raised considerably and the size can be brought down to practical limits, but the steam passing through entrains more and more water, as the rate of flow is increased.

With regard to the question whether it is better to operate compound reversing engines condensing or non-condensing, in the latter case using a regenerator and an exhaust steam turbine, it may be of interest to engineers to have a few data. At a recent test of a compound reversing engine at the Youngstown Sheet & Tube Co., the following results were obtained: Steam per i. h. p. hour, condensing, 21 pounds; non-condensing 33 pounds. This means that over 55 percent more is needed for non-condensing operation against purely atmospheric back pressure. I also uderstand that two compound reversing engines of another make in the Pittsburgh District use 35 and 55 pounds per i. h. p. hour respectively condensing, and non-condensing.* The ratio of saving by direct condensation is so overwhelmingly great, that a regenerator and turbine installation could scarcely produce similar results. Besides, the condensing engine means a simpler and cheaper installation.

DISCUSSION

Mr. C. H. Smoot:† Mr. Leahy's paper describes a very pretty and complete test of a regenerator.

I regret that the regenerator tested was not one of our type, as it constitutes a very thorough analysis of the performance of a regenerator in the hands of the user. It is to be hoped that some of the operators of our type of regenerators will some time see fit to make a similar analysis, so that the performance of the two regenerators can be compared side by side. The comparison of two such tests would show clearly how the engineering problems have been met in the different designs, and the success obtained with two different methods of solving the same problem.

*Proceedings Engineers' Society of Western Pennsylvania, Vol. 29, p. 445 et seq.

†Chief Engineer, Rateau Steam Regenerator Co., New York.

To me, one of the most interesting features of the paper is the clear exposition of the limits of the regenerator tested. Mr. Leahy has shown that its rate of steam absorption is very slow and that several minutes are required for the water of the regenerator to receive its full share of steam. The tests which we have made on regenerators, on the other hand, show that the rate of absorption is very rapid and in place of several minutes being required for the absorption to go forward, we consume only a few seconds.

The paper by Professor Hood shows an investigation of a regenerator which by all means does not work at all, owing entirely to its failure to absorb steam. I am very glad to learn that this apparatus has been improved since Professor Hood's tests and that some regenerative action is now obtained.

The papers of Mr. Leahy and Professor Hood both show clearly a regenerator which either does not operate at all or which can operate only in an imperfect manner, and also show the reason for the lack of perfection in its performance is due to an insufficiently rapid rate of absorption. Both papers bring forward very clearly the one fundamental and vital consideration in regenerator design, this being the water circulation.

In the water regenerator the heat absorbing capacity of the water determines the amount of steam which it will absorb. The rate at which the water circulation carries the water into the zone of condensation determines the rate of absorption for a given temperature between steam and water. Each pound of water passing through the zone of condensation absorbs a certain amount of steam, consequently the amount of steam absorbed in a certain time interval will be proportional to the quantity of water passing through the zone of condensation in the same time interval.

The design of a regenerator is quite bad, or indifferent, in proportion to the quantity of water which may pass through the zone of condensation in a given interval of time. To obtain a large quantity of water flowing each second through the zone of condensation requires either enormous velocities, which are impractical from the energy point of view, or very large conduit areas must be provided for the passage of the water.

The exceedingly slow rate of absorption disclosed by Mr. Leahy's paper for the regenerators which he tested is due to the restrictions placed in the water circuit. Referring to the drawing of the regenerator, it will be noted that all of the water which is mixed with the steam must pass through piping and valves. If these pipes were made ten times their cross-sectional area, the rate of absorption would be ten times what it is, but would still be much lower than is obtained in the Rateau type of regenerators, in which the area of conduit for the water circulation is one-half the entire horizontal cross section of the regenerator vessel.

Water is a poor conductor of heat and consequently in order to transfer heat from steam to water a large surface of contact must be provided, and the water must be brought in intimate mixture with the steam. It is not sufficient to have plenty of water in the regenerator vessel ten feet, or even half a foot away from the incoming steam; in order that all of the water within the vessel may be useful for the absorption of steam it must all be brought into intimate contact with the steam. The slow rate of absorption observed by Mr. Leahy is due to this condition; i. e., only a small portion of the water at one time can be mixed with the steam.

If the regenerator cannot absorb steam, it cannot give any steam off, and its effectiveness during an interruption in the supply of exhaust steam is determined by its effectiveness for absorbing steam during a surplus.

Regenerators in commercial service frequently operate with a temperature difference of one to two degrees Fahrenheit between incoming steam and water. With a two degree temperature difference, approximately 500 lb. of water are required to condense one pound of steam, and this 500 lb. of water must be brought in intimate contact with the steam. One pound of water heated two degrees absorbs 2—B. t. u.; one pound of steam at atmospheric pressure has a latent heat of some 1000 B. t. u.; consequently 500 lb. of water heated two degrees can condense one pound of steam.

If the flux of water be less, the temperature difference must be greater, and the effectiveness of the regenerator reduced.

Thus, 100 lb. of water passing through the zone of condensation for each pound of steam require a temperature drop, or difference, of 10 degrees Fahr. between steam and absorbing water.

The regenerators tested by Mr. Leahy and Professor Hood fulfill only part of the necessary conditions for absorption. In the spraying chamber, the water is finely divided and brought in intimate mixture with the steam, fulfilling this part of the requirements, but the quantity of water so introduced is totally inadequate for rapid absorption.

In the regenerators illustrated in Fig. 17, the entire water contents of the vessel can pass through the zone of condensation every few seconds, which makes it very easy to obtain 500 lb. of water and more for each pound of steam to be condensed.

In a regenerator vessel such as would ordinarily be used in connection with a 1000 kw. turbine, from 50 to 100 tons of water are contained. Ordinarily, we would use about 50 tons. This weight of water can pass through the condensing zone every two or three seconds, which means a water flux of over 1000 tons of water per minute, this condition being adequate to maintain a two degree temperature difference between steam and water.

If it were attempted to pass any such quantity of water as this through piping, the size of the pipe would be enormous, and the regenerator vessel would be a physical impossibility.

Figure 17 shows a diagrammatic cross section of the Rateau regenerator. The entire horizontal cross section is divided into four conduits for the upward flow of water and three passages for the downward flow of water. The cross sectional area for the water circulation in the upward circuit measured in square feet would be the total width between baffle plates and narrowed portion of mixing tubes, multiplied by the length of the vessel.

A regenerator suitable for a 1000 kw. turbine would be at least 9 ft. in diameter by 50 ft. in length, and the cross sectional area for the water circuit would be some 200 sq. ft., equivalent to a pipe 16 ft. in diameter. It is this large area through which the water circulation passes which permits the rapid absorption rate in this apparatus.

The experiments of Professor Trinks, while interesting, are not pertinent to the regenerator problem, since the method by which the experiments were conducted did not allow for a suitable water circulation. The phenomena to which he calls our attention has as one of its principal dimentions the rate of water circulation. If in his fish bowl the water circuit was arranged on a sufficiently large scale and suitably proportioned for a conservation of the water motion, he would have discovered that the rate of circulation depended upon the quantity of steam introduced, and the limiting condition which he took for his first series of investigations being the point at which the "flame" of steam just reached the surface of the water would have been greatly increased because of a better water circuit.

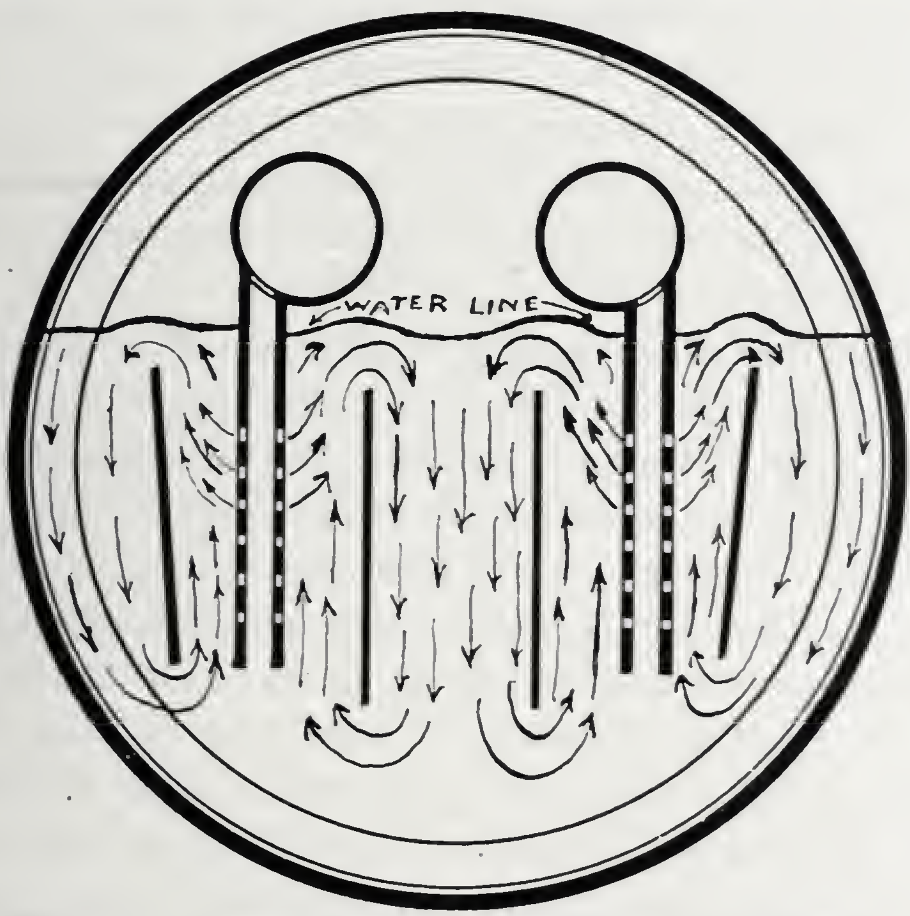

Fig. 17. Cross Section of Steam Regenerator.

Furthermore, in all regenerators which are used for practical purposes, there is invariably a passage of some steam through the regenerator, so that the actual working of the regenerator is the condition which he noticed, in which there was very violent turmoil, due to the bubbles of the steam bursting from the water.

This latter condition is the only one which is in any wise

pertinent to the regenerator problem, for when the passage of steam through the regenerator is relied on for water circulation, it is the passage of the steam in part through the water which determines the rate of heat absorption of the regenerator.

Professor Trinks' experiments, therefore, are conducted on the basis, and prime assumption, that the regenerator is not to work as a regenerator, but merely as a feed water heater, in which heat is added to water without the steam flux regulation which is one of the large points of difference between regenerators and feed water heaters. This latter point is also the explanation for his failure to verify the experimentally determined law of Mr. Gasche: viz: That the rate of steam absorption in the induced circulation regenerator is proportional to the temperature difference between the water and steam. He has failed to verify this observation through his failure to provide the essential consideration that the apparatus is to be a regenerator and that, therefore, steam passes through the vessel and maintains a water circulation which varies with the quantity of steam.

The difficulty which Professor Trinks experienced in making experiments with the fish bowl apparatus when steam was passing through the water is due entirely to the size of the vessel employed. He observed under these conditions that the water of the vessel was entrained and carried away by the steam. In practical regenerators the steam discharged is usually dry and very rarely contains as much as one percent of moisture. This condition would have been realized, had his vessel been equipped with a steam space several feet higher, which would permit the gradual separation of the steam and water.

In a practical regenerator, the absorption and regeneration of steam are always going forward more or less simultaneously. Steam entering the vessel beneath the water level is at slightly greater pressure than steam above the water and heats some of the water up to the critical temperature for this greater pressure. The condensation takes place in a rising column of water and the water which was heated at the lower portion of the vessel, on reaching the upper portion comes to a lower critical pressure and gives off some of the steam which has been ob-

served at the lower point. This gives rise to simultaneous absorption and regeneration, the absorption taking place under the influence of a static head of water, which is later removed, allowing for a partial re-evaporation.

For this reason a given bubble of steam at the lower point of the condensing zone might be large; condensation would occur, reducing its size; the bubble rising through the water, however, reaches a point of lower pressure, which gives rise to the re-evaporation of steam on the surrounding walls of the bubble and increasing its size.

It is this same phenomena which explains that a regenerator can give off all its steam during its regenerative period, as the circulation is maintained by the evolution of steam in the rising column of water, only the water having initially a circulation, reduction in pressure causes the rising column of water to evolve more steam than the descending column, since in the descending column the pressure on the water is being increased by the static head above. In the ascending column, however, the water is coming to lower and lower pressures, which favor the evolution of steam at this point. The steam bubbles forming in the rising column of water accelerate its circulation and thus maintain the movement of water during the regenerative period so that all of the water contents of the vessel come to the surface, or point of lowest pressure, in its passage around the water circuit.

It is interesting to note that the regenerator tested by Professor Hood after the hoist had been lifting men, and run for a long interval, gave off quite an appreciable amount of steam during the regenerative period, while in working under ordinary conditions, hoisting ore, the hoisting engine working for a very short interval, but very little steam was regenerated. The reason for this difference in action is obviously due to the defective water circulation of the regenerator, the quantity of water brought into the zone of condensation being too small and requiring a long interval for the storage of an appreciable amount of steam to be given off during the regenerative period. This longer interval of steam surplus was provided when hoisting men, but during the ordinary working, when hoisting ore,

the engine did not run long enough to provide an accumulation of steam within the vessel. If the quantity of water passing through the zone of condensation in this regenerator had been adequate, no perceptible difference in the regenerative action would be noticed and the regenerator would give off its full storage capacity of steam in each interval of hoisting.

Mr. John A. Hunter:* We have installed at one of our plants two regenerators of the Rateau type. One of the regenerators is eight feet in diameter by 40 ft. long and has a capacity of 90 000 lb. of water. This regenerator was installed about five years ago. The other regenerator is nine feet in diameter and 50 ft. long and has a capacity of 126 000 lb. of water. It was installed about two years ago. With the first regenerator there was also installed a low pressure 500 k. w. turbine. At that time the steam for operating the turbine was taken from a 45 in. by 72 in. blooming mill engine. At the time of the installation of the second regenerator, two mixed pressure 500 k. w. turbines were installed and the steam from two 44 in. by 48 in. bar mill engines exhausted into the system. The general arrangement is somewhat as follows:

All the exhaust steam is passed through an oil separator on the end of a 9000 h. p. open feed water heater. The steam required for heating the feed water is drawn into the heater, the remainder passing over into a receiver located between the ends of the regenerators, from which point the steam is distributed into the two regenerators the surplus being wasted through a relief valve on top of the receiver. As the mixed pressure turbines use high pressure steam more economically then the low pressure turbine, it was deemed advisable to have these turbines operate on high pressure steam a greater proportion of the time than the low pressure turbine. This was accomplished by installing valves between the mixed pressure turbines, and regenerators which would close when the pressure in the system dropped to 0.5 pound, the governor of the mixed pressure turbine operating the high pressure steam valve. There is an electric controlled double valve in the line to the low

*Mechanical Engineer, American Sheet and Tin Plate Company, Frick Building, Pittsburgh.

pressure turbine which closes when the pressure drops to about 0.25 pound, and at the same time opens the high pressure steam line which admits steam through a reducing valve at about 0.25 pound pressure.

Some time ago we undertook to make a test on the entire system, similar to the test conducted by Mr. Leahy. When temperature charts were taken from the two regenerators it was found that the small regenerator was doing very little work. An examination showed that some of the baffle plates had been broken, so that the proper absorbing effect could not be obtained. These plates have been replaced, but due to weather conditions we have been unable to make any complete tests. However, a series of tests were made shortly after the installation of the first regenerator and turbine. On an eight hour test with the turbine operating at about its rated capacity the regenerator supplied steam to operate the turbine after the reversing engine had stopped for periods varying from two minutes to three minutes and ten seconds as a maximum. The length of the regenerative period was of course some function of the temperature of the water in the regenerator at the beginning of this period, and would depend on the length of the absorbing period and the back pressure in the exhaust system just previous to the regenerative period. The back pressure varied from nothing to about 7½ pounds. Since the installation has been completed the back pressure has been reduced to about 4½ pounds as a maximum.

Mr. J. A. McCulloch:* Under the circumstances of this evening's discussion I had not expected to be called on. Tonight's proceedings have been given as a discussion of Mr. Gasche's paper and we are fortunate in having presented detailed experimental data, for I fear that cursory reading of that excellent paper might lead to the idea that speedy absorption is a necessity for practical success. Indeed, this idea has been expressed by others and some emphasis has been placed thereon.

We may question whether such idea is correct. If it is tenable it would imply that the McKeesport regenerators are a failure but Mr. Leahy's experimental results indicate that they

*Mechanical Engineer, National Tube Company, McKeesport, Pa.

are a practical success even though they are very slow absorbers. A success, because they seldom waste steam to atmosphere except in the occasional event of the two mills operating in unison, delivering more steam to the system than the turbines can dispose of as is evidenced by the fact that the live steam valve does not then open within the cyclic time interval which the system was planned to tide over by its "fly-wheel-action."

The conception that speedy absorption is requisite appears to be founded on the idea that the energy required to cause circulation must be taken into account in the calculation for the forced type but for the induced type may be ignored. In case the forced circulation is produced by external energy which is relatively great compared to the energy equivalent of the increased steam consumption caused by the back pressure which induces circulation, then the latter may be relatively negligible, but in both the designs exhibited tonight the circulation is caused by back pressure. One design is of the forced type while the other is of the induced type. In the one type, the steam required by the turbine is by-passed to it without causing much back pressure but the excess steam causes a back pressure that admits water sufficient to condense the excess. In the other type, all the steam is forced through the water and out of the submerged orifices, the steam required for the turbine being obtained by re-evaporation. Both types causes back pressure but one type absorbs slowly while the other type absorbs speedily.

The great similarity of the pressure charts exhibited indicates that there is reason to question whether speedy absorption and re-evaporation of the running demand is more economical than to by-pass that portion and slowly absorb the excess; —whether speedy absorption is a necessity.

The great similarity of the two types both obtaining absorption at expense of back pressure, both doing this in a practically effective manner and both at a marked similarity of back pressure, indicates that whatever evaluating process or mathematical analysis we use to determine the energy causing absorption in the one type must also be used for the other type.

We shall look eagerly forward for papers giving similarly full experimental data of tests of other installations.

MR. L. LEE:* I am not prepared to express an opinion on the subject, as our regenerators, installed some four years ago, are in the same shape as the one mentioned by Mr. Hunter.

Comparing a simple reversing engine, exhausting through regenerators to mixed pressure turbine, and a compound condensing reversing engine, there is no question in my mind that the last named installation will give better economy.

The fact that, after running an installation with regenerators and mixed pressure turbine, we installed a compound condensing engine on our last blooming mill shows how we feel.

The points Prof. Trinks brought up are very interesting, although I hardly think a test on a small scale like that can compare with actual operating conditions.

I think that, with the proper installation of regenerators and mixed pressure turbines, such an installation would show a saving over old installations of simple engine running free exhaust of not 100 percent but probably a very good percentage on the investment.

MR. L. BATTU:* Mr. Hood's paper is a very interesting illustration of what results can be expected from the forced circulation and induction types of regenerators.

The curve shown of the forced circulation regenerator working on exhaust of hoisting engine is a perfect demonstration that the apparatus did not fulfill the duty it had to perform.

Mr. Hood states further that the apparatus was changed and worked better. The alteration made in the apparatus consisted primarily in suppressing the forced circulation and using induction instead. The way the induction method was applied was very crude and the results were consequently very mediocre, although an improvement was observed.

With a well designed type of induction regenerator there is no doubt, and this has been demonstrated in hundreds of installations, that all the steam of the hoisting engine could be used in a low pressure turbine and create a very material saving.

*Chief Engineer, Youngstown Sheet and Tube Company, Youngstown, Ohio.
*President, Rateau Steam Regenerator Company, New York.

Referring once more to Mr. Hood's request that some form of guarantee be given for the benefit of customers purchasing steam regenerators, I would suggest that the most practical guarantee which can be given on a regenerator consists in measuring the pressure at the inlet and outlet of regenerator when steam is flowing through it, thus obtaining the loss accountable for passage of steam through regenerator itself and also to measure the time which elapses before the entire mass of water contained in the regenerator arrives at its maximum temperature. Obviously, the loss of pressure should not be greater than a pound at the utmost and the time required to heat the entire mass of water from the lower to the higher temperature should not exceed a few seconds.

In measuring the time necessary to heat the water in the regenerator, steam should be allowed to flow in and out of the regenerator in order that the water circulation be maintained. If approximately ten percent of the steam is allowed to flow out, this should be quite sufficient to realize operating conditions at their worst and give a thorough test under most severe conditions to the apparatus.

The above tests could be made by the reading of gauges and thermometers, and there is no difficulty for an engineer to realize exactly what the apparatus is doing.

Prof. Trinks has made tests which show quite well that in designing regenerators, like any other type of apparatus, proportions cannot be disregarded.

The writer had the opportunity about twelve years ago to see through glass panes the interior of a regenerator working on a hoisting engine exhaust. Powerful lamps had been placed in the regenerator and it was possible to see the extremely violent circulation which takes place in these machines.

The steam was not in bubbles but in jets and the agitation due to the rush of water was such that it was quite impossible to perceive the shape of these jets.

It is quite true that at the point where the steam is discharged from the water there is a very heavy swell, a kind of wave formation. This in itself is a most efficient way of mixing steam and water.

Regarding the quality of the steam passing through the spray of water, it is, generally speaking, dry saturated steam; remarkably dry steam. This is in no way difficult to understand as the velocity of the steam in the regenerator is low and the water is not entrained, as the drops are quite large relatively.

The water contained in steam which can be separated with difficulty is the water in the shape of mist. There is no such thing in a regenerator. All the mist is absorbed by the passage of the steam through the water.

Three very accurate tests have been made on steam regenerators having widely varying duties. The first showed dry saturated steam; the second showed 0.32 of one percent, and the third showed 1.02 percent moisture. The last was made in a regenerator where the enormous volume of steam as compared with the amount of water contained indicated that the limit of prudence had been reached, to say the least.

It was stated tonight that back pressure due to regenerators was the same with the induction type or forced circulation. This is quite an impossible suggestion.

It is materially impossible to realize that the same amount of power should be expended to circulate water without lifting it as to circulate it several feet above its surface in the same quantity for the same expenditure of power.

A large number of regenerators have been used to regulate the steam discharge of reversing engines discharging into central condensers. It is customary to guarantee in such instances that the loss of pressure due to passage of steam through the regenerator will be less than one-fifth of a pound and that the vacuum in the condenser will not vary more than $\frac{1}{16}$ in. of mercury. These results show plainly what can be expected of regenerators.

Regarding Prof. Trinks' statement that the thermic efficiency of a compound condensing reversing engine is superior to a compound reversing engine with regenerator and low pressure turbine combined, I beg to differ.

Very recently several new steel plants have been built with the latter combination and the figures given by Prof. Trinks as

to the performance of the compound condensing engine would not have been sufficiently attractive to overcome the advantages offered by the combination of gas engines and electric motor drive.

Regarding compound reversing steam engines, it is quite customary abroad to use a steam regenerator working on steam pressure ranges far below atmosphere in such a way that the compound engine works with an exhaust a few pounds under atmospheric pressure.

It is self-evident that in plants well designed steam turbines must be capable of using all the steam discharged by the mill engine and that all overloads or steam deficiencies be taken care of by high pressure steam used with great economy in the turbine, which must be built of the mixed pressure type; i. e., having high pressure wheels as well as low pressure wheels, and having regulating means which respond both to pressure in the low pressure source just as well as to turbine speed.

Prof. Hood has suggested that the range in pressure on the regenerator system which controls the back pressure on the reversing engine itself be such that it should vary in inverse ratio to the turbine load. Such a device was patented some four or five years ago and has been used in a few plants.

The loading of the relief valve is subjected to the action of a piston, which is actuated on one side by steam before the throttle valve to the turbine, and on the other side by steam taken behind the throttle. In this way the operation of the relief valve is dependent on the amounts of steam flowing into the turbine.

MR. C. H. SMOOT: Speaking of regenerators, there is a very important matter, from the point of view of economy, in a proper use of high pressure steam in the low pressure turbine. Some types of turbines are not equipped with high pressure elements, which can operate efficiently on high pressure, and in almost all regenerator installations there occur periods when it is advisable for one reason or another to maintain the turbine in operation, even though the supply of exhaust steam be inadequate. If the turbine as a high pressure machine is inefficient, there would be a loss of money during its high pressure operation,

which will detract from the economy of the plant when operating on low pressure. In connection with the economical use of high pressure steam in a low pressure machine, the regulation is a matter of importance in that the high pressure steam must be admitted only when the low pressure steam is deficient and in a quantity sufficient to maintain the load of the turbine without disturbing its speed. The mixed pressure turbine is adapted for this purpose and is so arranged that the turbine runs always on low pressure steam so long as there is available a sufficient supply and automatically takes just enough high pressure steam to compensate for the deficiency in low pressure steam. To obtain all of the money value of the high pressure steam used under these conditions, the turbine must be an efficient high pressure machine and this requires that it be equipped with a separate high pressure element, which is brought into action only when passing high pressure steam.

The use of regenerators is not limited to driving turbines and very great economies can be obtained from their use for the purpose of heating boiler feed water from an intermittent engine exhaust, as the regenerator can be made to equalize the flux of steam from such an engine sufficiently to permit its effective use in a feed water heater whose arte of steam absorption is necessarily limited and cannot be made to vary as rapidly or through such wide limits as the flux of steam from the intermittent engine will vary.

CORRESPONDENCE

Mr. F. G. Gasche*: The investigation by Mr. Leahy is the most complete test of regenerator action of which a published statement has been made, and the contrast with many other "experiences" is shown by the broad minded liberation of this splendid array of experimental data to the Proceedings of the Society.

After a search through the tabulated results, which are clearly shown so far as fundamentals are concerned, it is manifest that the experiments and calculations have imposed a large

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amount of work above the requirements of simple commercial testing. By this application on the part of Mr. Leahy and his associates the indications of theoretical work have been checked by actual observations on full sized apparatus.

Considering the difficulties in controlling the action of such a large installation so that test conditions can be maintained, and in collecting data originating in simultaneous observations by a group of assistants widely separated by their individual duties, I think it highly creditable that the consistency of results shown in Tables No. 2 and No. 3 is realized. The manner in which the experiments were made in order to arrive at definite values for the quantity Δ is ingenious. Without a review of the matters related to this characteristic it is alone an indication of a surprisingly low heat storage capacity considering the physical dimensions of the installation. I was disposed to credit this type of regenerator with higher values.

Mr. Leahy has evaded the estimate of the value of H^1 and for a sufficient reason. It may be suggested that the increased back pressure due to the spraying apparatus alone, as distinguished from the overall back pressure of the regenerator equipment, is an added load on the engine. If the steam rate of the engine is known the heat equivalent of the work done against this back pressure is an approximate value of H^1. In any case the experiments and calculations must deal with an actual plant equipment.

Table No. 3 gives the "efficiency of regenerators" as measured by ratios suggested in the "Theory", and is remarkable for the relatively small variation of efficiency for widely different demands on the regenerator as shown in the column headed "Actual Heat Storage". As in all probability a "perfect" regenerator absorption will not be found in any commercial apparatus, it seems that the "efficiency of regenerator" will yet become a reasonable measure of the commercial value of a given type and size of regenerator equipment.

Table No. 1 gives pressures at the steam pipe near the turbine varying from 1.48 lbs. to 5.56 lbs. The best turbine performance, as measured by thermal efficiency, seems to conform with 2.73 gauge pressure at this point. Judging from the

statement of average and maximum back pressures imposed on the engines, before and after the application of the regenerators and turbine, there is a loss of pressure due to the regenerator and piping somewhat exceeding 5 lbs. per sq. in. when both mills are in operation. This may not be a fair comparison of average pressures, but there seems to be a sufficient pressure loss on account of the regenerators to demand further inquiry. Having personally examined the regenerator and piping installation at the McKeesport Plant, I have no hesitation in saying that it is a most exceptional design in the way of large exhaust piping and large radius of bends. The loss of pressure indicated by this test data can, in all probability, be charged to the resistances of the spray chamber as employed in this type of regenerator.

Item 38 of Table No. 1 is a sufficient answer to all those advocates of compound condensing reversing engines who would substitute the attainable performance of a low pressure cylinder and condenser for the present exhibit of low pressure turbine and condenser, concerning which further details will be offered in what follows.

If definite information is at hand concerning the momentary steam delivery from a group of engines, there is immediately an available quantity constituting a leading item in regenerator specifications. This item is the *maximum rate of steam delivery to the regenerators, together with the time during which this rate is maintained.* A specification of regenerators should have as its first requirement the following clause; viz., "The regenerator must be capable of heating the entire body of water from a temperature t_1 to a temperature of t_2 in a time θ_1 seconds with the steam supply maintained at a temperature T and with steam delivery meanwhile of m lbs. per minute." A second clause should read as follows: "The regenerator must be of sufficient capacity to deliver M lbs. of steam per minute for θ_2 seconds without the influx of live steam, the temperature of the water falling from t_2 to t_1."

It is to be noted that t_2 cannot be the same as T for any limited time as the "Theory" shows, and reasonable dimensions would be obtained by allowing $t_2 = 0.95\ T$ to $t_2 = 0.98\ T$ with $m = 0.1\ M$.

A third clause should require specific guarantee that the resistance imposed on the engine by the generators shall not exceed a certain specified amount.

It is not a matter of grave concern if the back pressures on the engines are high, provided they are realizable with a small reduction at the turbine valves. This arises from the fact that the turbine is far more economical than any practicable low pressure cylinder with condenser can be. There is, of course, a practical limit to the back pressure that may be imposed on a given engine with a given load, i. e., the capacity to do its work. Up to this point there is no detriment to the plant as a whole *provided the output of the mixed flow or even low pressure turbine can be utilized.* Given this latter provision the output of engines, regenerators, and turbines is greater for the same amount of steam than any condition involving lower back pressures on the engines. With the limited turbine output for the installation to which Mr. Hood refers it did not require much increase of back pressure on the engines to cause a notable loss to the plant as a whole.

The researches of Professor Trinks are interesting and are of the order worthy of encouragement, but he seems to have arrived at the conclusion that tests of this nature should be left to the builders of regenerators though it is not clear why the splendid researches like that of Mr. Leahy will not serve the purposes.

With all of Professor Trinks' derived results before us it remains to reconcile the facts with his conclusions. Mr. Leahy has shown that his regenerators do absorb large quantities of steam without wastes at relief valves except for the local circumstance of two mills in operation involving the delivery of more steam than the turbine could use. The moisture in the steam is shown in Table No. 1, row 9, and never exceeds 1.70 percent. Why will this render the operation of the turbine dangerous? Enough direct evidence has been presented in the discussions on the "Theory" to show positively that the regenerator is uniformly a good steam separator in reducing the moisture originally present in the exhaust of the engines. A reiteration of the statement that regenerators deliver steam so heavily

charged with moisture that the operation of turbines therewith is dangerous would not seem admissible before the Society.

There are at least three plants in this country where the absorption of steam during peak loads on the engines is such that the lifting of relief valves is very infrequent, and may be called an event.

Considering the limited heat storage capacity of the receiver spaces, the enormous peak load steam deliveries from the engines, and the variable load on the turbines, there is no other place for the excess heat to go than to the water in the regenerators. In view of these exhibits Professor Trinks' conclusion, that regenerators must have the extraordinary dimensions derivable from his experiments, does not apply—at least to full sized commercial installations.

So far as direct experiment on a full sized "forced circulation" regenerator is concerned we no longer have to rely on a more or less hypothetical, illustrative case, but the latter, when introduced with the "Theory", has proved to be more than conservative. Pending the publication of experiments on regenerators with "induced circulation" we might, for the sake of material progress, proceed to calculate the surface exposure of steam to water on the supposition that those surfaces will be called "flames" instead of "bubbles" and "jets", but the ultimate result will be a surface exposure of enormous extent. Here, again, the full sized apparatus will exhibit conditions peculiar to the dimensions. Let actual experiments on regenerators establish the value of the important constant K.

The method by which the benefit due to the use of a condenser on a compound reversing mill engine as calculated by Professor Trinks is worthy of attention. The difference of 33 and 21 divided by 21 is indeed over 55 percent, but why stop the calculation at this point? No reversion from condensing to noncondensing practice would be undertaken with such a loss if the atmosphere were the final disposition of the steam. A delivery of this steam to mixed flow turbines would, in all probability, produce an output of engine and turbines at least double the condensing output of the engines provided use could be found for the energy delivered by turbines.

Examine the performance in another way. Suppose the compound reversing engine is running noncondensing, then on the basis of the alleged performance of the engine the saving by condensing operation is the difference of 33 and 21 divided by 33 or 36.3 percent. If a mixed flow turbine is applied to the engine the energy output would be doubled, and the steam per horse power delivered would be 16.5 lbs., approximately, for the whole plant provided the full output of the turbine could be utilized.

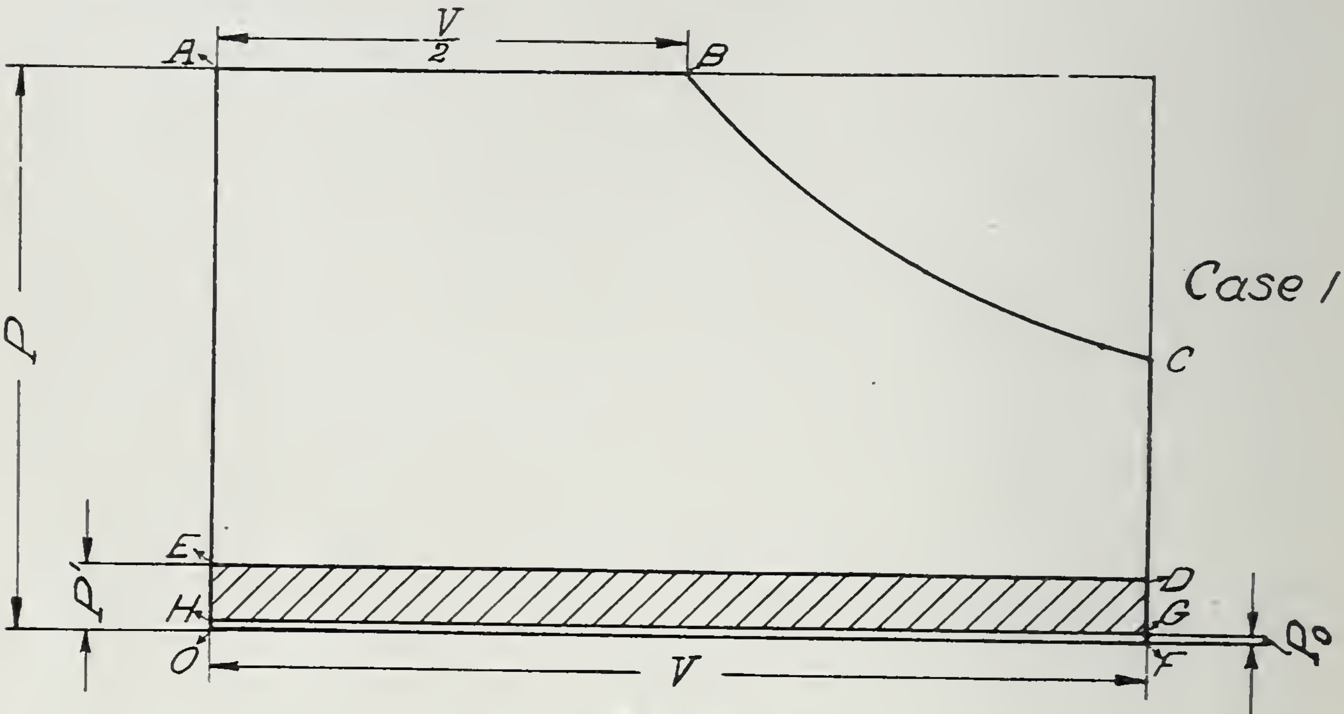

Fig. 18.

All this is premised upon the alleged performance of the Youngstown engine with condensing vs. noncondensing operation, but the values 33, 21, and 36.3 percent, as derivable therefrom, are at least incompatible since the saving of 36.3 percent by the mere application of a condenser is greater than that of a perfect engine and condenser operating with ideal loads. That particular engine will operate with an economy somewhat between the exhibits of an engine with two expansions and another engine with 9.2 expansions of steam for full or average full load conditions. Since exact test data concerning pressures, clearance volumes, loads, and other controlling factors are not at hand it is necessary to make estimates of the benefit due to condensing operations under conditions so nearly ideal that they cannot be approached by any actual engine. These conditions have long since passed as elementaries, but they will

bear repetition if they keep from future appearance in the Proceedings of this Society any statements that the mere application of a condenser will be the means of saving 36 percent or more of steam.

THEORETICAL LIMITS OF STEAM SAVING DUE TO CONDENSING OPERATION OF ENGINES

Case 1. Fig. 18: An initial absolute pressure P, and absolute back pressure P^1, a ratio of expansion of 2, and a volume of low pressure cylinder V. The work done by a perfect steam engine can be represented by the area,

$$\begin{aligned} A\,B\,C\,D\,E &= O\,A\,B\,C\,F - O\,E\,D\,F \\ &= P\,V\,(0.5 + 0.3465) - P^1\,V \\ &= V\,(0.8465\,P - P^1) \ldots\ldots\ldots\ldots\ldots\ldots (1) \end{aligned}$$

For condensing operation and the *same* amount of steam admitted to the cylinder the work can be represented by area

$$\begin{aligned} O\,A\,B\,C\,D\,F &= O\,H\,G\,F \\ &= V\,(0.8465\,P - P_0) \ldots\ldots\ldots\ldots\ldots (2) \end{aligned}$$

The increase of work due to condensing can be represented by the area

$$H\,E\,D\,G = V\,(P^1 - P_0) \ldots\ldots\ldots\ldots\ldots (3)$$

The percent of gain by condensing in work done for the same amount of steam is expressed by

$$\%\ Gain = 100.0\,\frac{V\,(P^1 - P_0)}{V\,(0.8465\,P - P^1)} \ldots\ldots\ldots\ldots (4)$$

For an approximate numerical value assume

$$\begin{aligned} P &= 155.\ lbs.\ absolute. \\ P^1 &= 17.\ lbs.\ absolute. \\ P_0 &= 2.\ lbs.\ absolute. \end{aligned}$$

$$100.0\,\frac{P^1 - P_0}{0.8465\,P - P^1} = 100.0\,\frac{17.0 - 2.0}{0.8465 \times 155.0 - 17}$$

$$= \frac{1500.0}{114.2} = 13.13\%$$

Case 2. Fig. 19: Pressures and volume of cylinder same as for *Case 1* with the exception that complete expansion to the back pressure is realized in *noncondensing* operation. The work done by a perfect steam engine can be represented by the area

$$A\ B\ D\ E = O\ A\ B\ D\ F - O\ E\ D\ F$$

$$= V\ (P^1\ log_\epsilon \frac{P}{P^1} + P^1) - V\ P^1$$

$$= V\ P^1\ (log_\epsilon \frac{P}{P^1}) \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

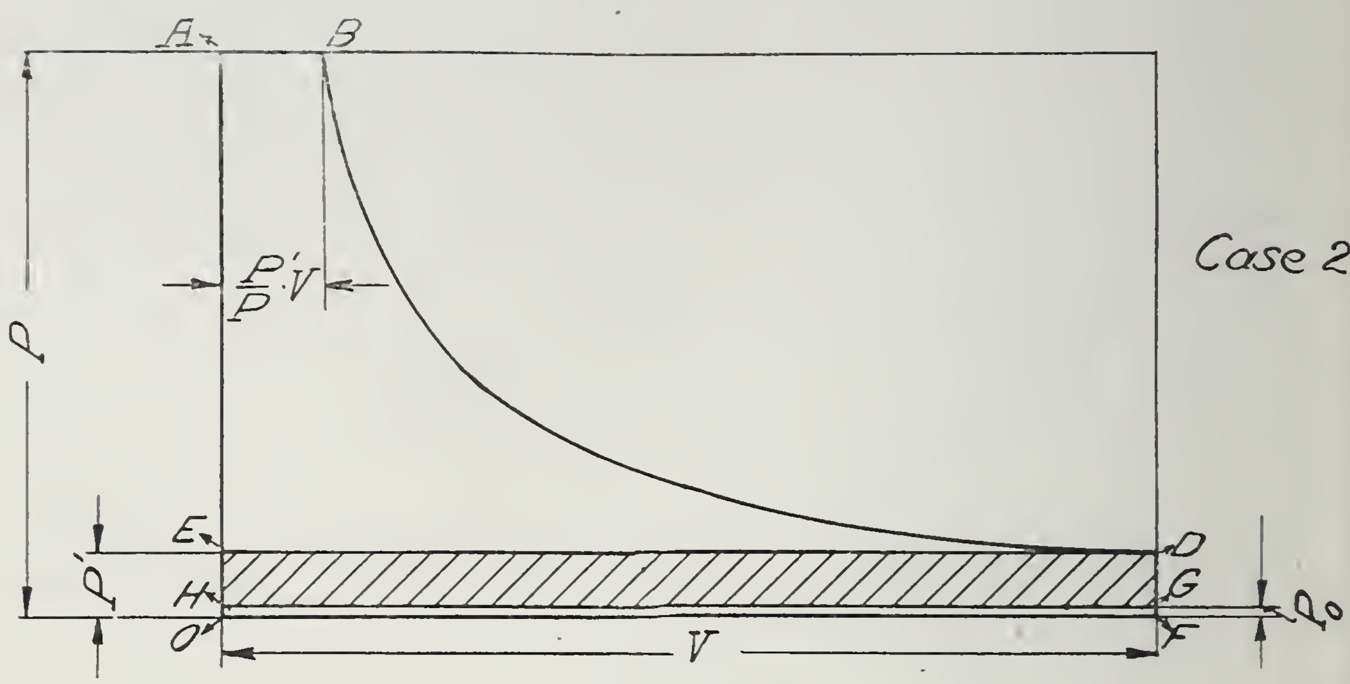

Fig. 19.

For *condensing* operation and using the *same* amount of steam the work done by a perfect steam engine would be represented by the area

$$O\ A\ B\ D\ F - O\ H\ G\ F = V\ P^1\ (log_\epsilon \frac{P}{P^1} + 1) - P_0\ V \ldots (6)$$

As before, the ratio of the areas $H\ E\ D\ G$ to $A\ B\ D\ E$ multiplied by 100.0 is the percent gain due to condensation, thus

$$\%\ \text{gain} = 100.0\ \frac{V\ (P^1 - P_0)}{V\ P^1\ (log_\epsilon \frac{P}{P^1})} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Using the numerical values for P, P^1, and P_0 as in the preceding case, we find

$$\%\ \text{gain} = 100.0\ \frac{17.0 - 2.0}{17\ (log_\epsilon \frac{155}{17})} = 39\ \%$$

The foregoing exhibit of the possibilities of reduction of steam demands in pounds per i. h. p. per hour is a legitimate derivation where the conditions at the plant are such that the additional power due to condensing operation can be utilized. It is based on the conditions attending the operation of an

engine unencumbered by throttling at the valves and ports. It implies nonconducting cylinders and ideally steady load conditions. Under the limitations of actual engines the energy represented by (3) is never realized and the values of (4) and (7) are consequently less than the limiting values shown for the numerical equivalents. For the second case and formula (7) the practical limits are about 25 percent and most frequently do not exceed 18 percent. The subject can be examined by the supposition that there is a readjustment of the steam distribution in an engine with condensing vs. noncondensing operation, thus providing for the *same load* on the engine in either case. With the notation as before we have to examine the steam demands of a perfect engine which, in noncondensing service, corresponds with the *Case 2* as compared with the conditions after the condenser has been applied.

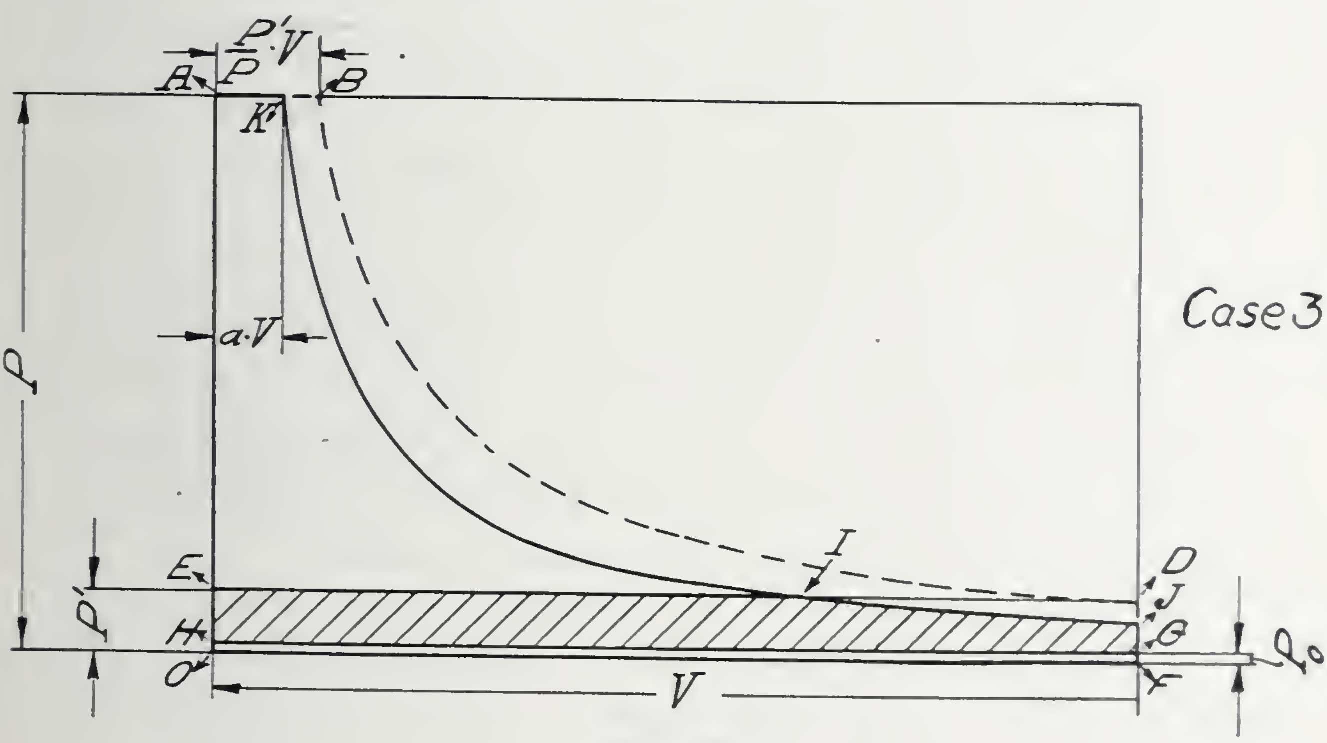

Fig. 20.

Case 3. Fig. 20: For noncondensing operation the work done is represented by (5).

For condensing operation the steam is cut off at a volume $A\ K = a\ V$ which is less than volume

$$A\ B = \frac{P^1}{P} V$$

on account of the area $H\ E\ I\ J\ G$ added below the back pressure line. The area

$$H\,A\,K\,J\,G = a\,P\,V\,(1 + \log_\epsilon \frac{1}{a}) - P_0\,V \ldots\ldots (8)$$

The work done whether condensing or noncondensing is now assumed to be the same, hence, equating (5) and (8)

$$P^1 \log_\epsilon \frac{P}{P^1} = P\,a\,(1 + \log_\epsilon \frac{1}{a}) - P_0$$

or

$$P\,a\,(1 + \log_\epsilon \frac{1}{a}) = P_0 + P^1 \log_\epsilon \frac{P}{P^1} \ldots\ldots\ldots\ldots\ldots (9)$$

The gain in percent due to condensing is represented by the ratio of the volumes at cut off.

$$100.0 \frac{A\,B - A\,K}{A\,B} = 100.0\,(1 - \frac{P}{P^1}a) \ldots\ldots\ldots\ldots\ldots (10)$$

Using the values of P, P^1, and P_0 as above an approximate value of a may be derived from (9) by trial and error which will be stated as $a = 0.06964$. The gain in the way of steam saving while maintaining the same load on the engine is therefore

$$100.0\,(1 - \frac{150}{17} \times 0.06964) = 38.55\%$$

Actual engines are encumbered by losses which will not be enumerated at this time except to remark that the performance of an ideal engine is far from realization by any reversing engine subject to variable loads. The gain has frequently been observed as 15 percent or even 18 percent, but 25 percent is yet to be exhibited as an authentic performance.

MR. H. C. SIEBERT:* In Mr. Leahy's paper, it is interesting to note in the case of the slabbing mill engine which exhausts 100 000 lb. steam per hour, which is sufficient to operate the turbine at full load, that it is seldom that any exhaust steam escapes into the atmosphere and that the valve admitting high pressure steam into the regenerator is open only 2.6 minutes per hour, or 4 1-3 percent of the time. This data leads to the conclusion that the capacity of the regenerators is sufficient to meet the operating conditions of that particular plant.

On two installations of regenerators and exhaust steam tur-

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bines connected to simple reversing engines of blooming mills in operation in two plants in the Youngstown district, I have observed that the regenerator atmospheric relief valve opened at about the instant in which the engine throttle was opened, that it remained open during the full time period of nearly every pass, when steam was exhausted into the atmosphere at 5 pounds gauge and more, when the back pressure in the cylinders varied between the limits of 7 and 15 pounds gauge. Besides, but a very short time elapsed between the closing of the regenerator relief valve and the opening of the valve which admitted high pressure steam into the turbine. During the time that these observations were made both mills operated under normal conditions rolling three ton ingots to 6 in. by 6 in. blooms. The longest delay between two consecutive ingots was about three minutes.

The regenerator in one plant seemed rather small for the conditions, but in the case of the other plant the regenerator consists of three large vessels which seem fully as large as the installation described by Mr. Leahy. If curves of back pressure on engine, time of opening of regenerator relief valve, and high pressure steam valve were plotted from the better of the two plants mentioned above, it would be found that the regenerator relief valve remains open for at least 30 percent of the operating time of the mill engine. These curves would be very similar to those shown by Mr. Hood, for the hoisting engine. In the cases mentioned above the steam losses seem abnormal. Whether or not they are caused by insufficient regenerator capacity, improper design of regenerator or its mechanism, circulation and heat absorption as shown by Prof. Trinks, or other reasons, I will not discuss; the fact remains that such installations yield a poor return on the money invested. Thus, while the plant as described by Mr. Leahy is operating with but slight losses, there are other plants where the losses are quite large. The words of Mr. Hood, that, "with increasing back pressure there comes a condition where a saving at the exhaust end of the operation is more than offset by the cost of the added steam needed by the main engine and the added auxiliaries", touch a very important point in connection with exhaust turbine and regenerator in-

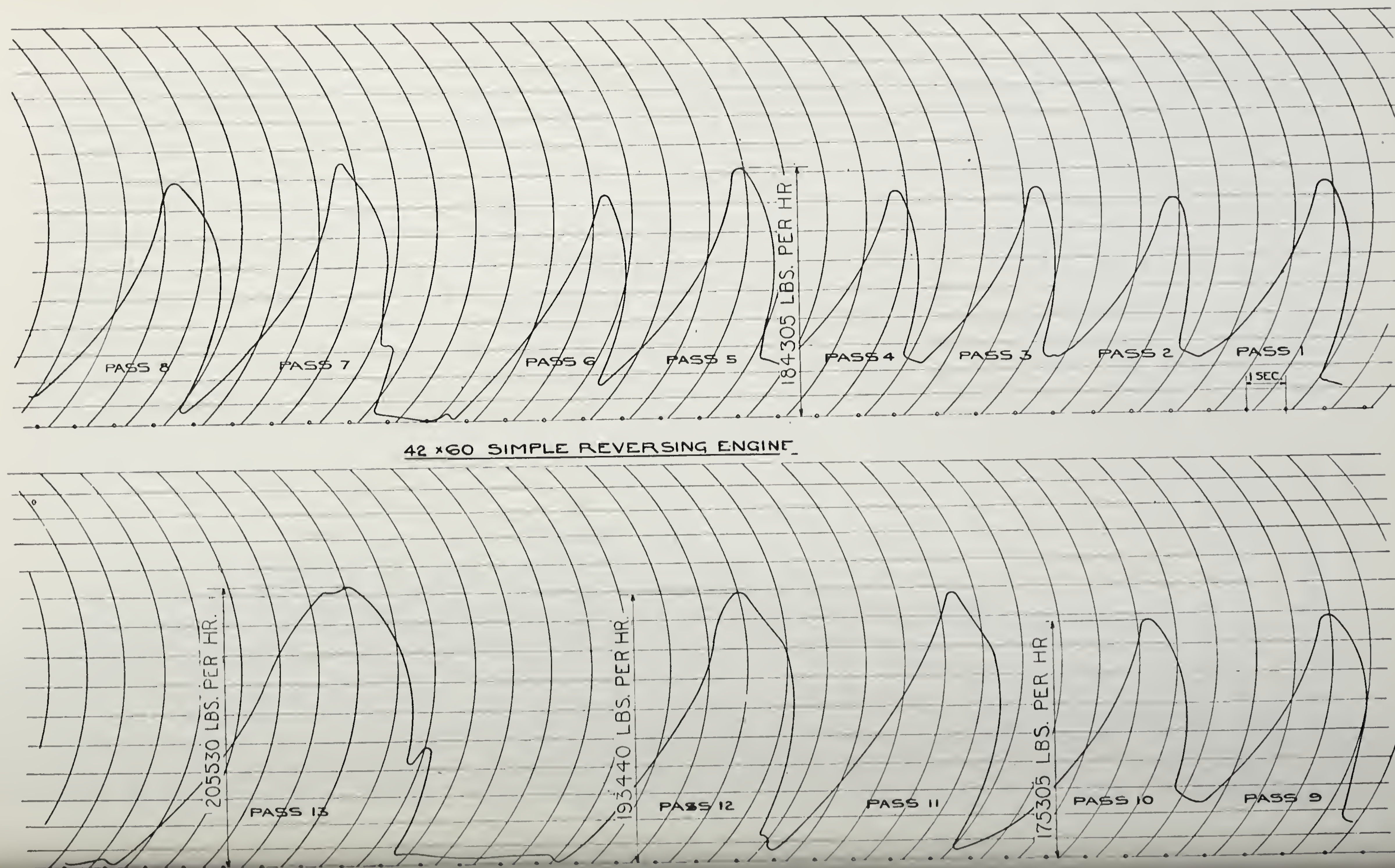

Fig. 21. Steam Meter Record from 42 × 60 Simple Reversing Engine.

stallations. All such installations increase the back pressure on the engine, and on this increase depends to a considerable extent, the success or failure of the whole combination. In recent years a number of exhaust steam regenerator and turbine plants have been added to reversing mill engines. For some of these success is claimed; for others failure. All tests published to date, with one exception, give data for the turbine economy, but none for the economy of the engine before and after the installation of the turbines and regenerators, nor for the economy of the various types of engines operating under different conditions of back pressure. Some engineers seem to take for granted that any old steam "eater" is good enough for reversing rolling mills when combined with regenerators and low pressure turbines, which, making use of the engine exhaust, give power for nothing, and that better economy can be derived from such installations than from good condensing engines. For the purpose of showing that such a view is erroneous, I submit the following table of data which was obtained on a number of tests on reversing rolling mill engines of different types, operated condensing and non-condensing, and which shows their relative economy. Combining the figures given in this table with those quoted by the speakers of this evening, one can arrive at an estimate as to whether or not regenerators and exhaust steam turbines connected to a simple or compound reversing engine will yield a better return on the money invested than compound reversing engines operated condensing.

This is the question that interests rolling mill engineers, and on this question no information is given in Mr. Leahy's paper, which is almost entirely devoted to the performance of the turbine and its regenerators.

The figures in the last column of the following table check fairly well with the figures given by Mr. Hood for the hoisting engine, three percent for one pound reduction in back pressure.

The steam consumption per i.h.p. per hour was computed from continuous indicator cards, taking dry steam near point of release, 0.9 stroke, and adding 30 percent for cylinder condensation, valve leakage, and clearance losses .

ECONOMY OF REVERSING ENGINES OPERATED CONDENSING AND NON-CONDENSING

Engine			Operating Conditions	Steam consumption per I.H.P. per hr. With pressure at throttle 130 lb. gauge		Back pressure or vacuum. Lbs. gauge in cylinder		Saving in Steam due to running Condensing		Saving in % of steam for 1 lb. reduction in back press
Case	Cylinder dia. and stroke Inches.	Type		Non-Cond.	Cond.	Avge.	Max.	Per I.H.P. Hr.	%	
A	42×60	Twin Simple Reversing	Throttle Control No cutoff	45.0		2.0	6.0			
B	44 & 70×60	Twin Tandem Compound Reversing	do	48.0	32.0	1.2 11.0	7.0	16.0	33.3	2.73
C	46 & 76×60	do	Throttle Control & Cutoff	33.0	22.5	1.0 11.0		10.5	31.8	2.61
D	46 & 86×84 & 84×60	Cross Compound Corliss Blowing	Cut-off Governor	25.7	17.2	0.5 10.5		8.5	32.3	2.94

For variation in back pressure steam consumption for Cases *A* and *B* see respective curves Figs. 21, 22 and 23. The exhaust piping of these engines is large in diameter, very short, and contain few bends of large radii, yet the curves of back pressure vary within wide limits, in short intervals of time. Those who wish to figure regenerator problems may also find useful these accompanying curves of steam flow for reversing engines of blooming mills.

The slabbing mill engines described by Mr. Leahy operated against a back pressure of 1.1 lb. gauge before being connected to the turbine plant; after combination with that plant the back pressure increased to an average of 5 lb. gauge, above atmosphere. As an example of the economy that can be derived from a simple or a compound reversing engine combined with regenerators and exhaust steam turbines, I will employ in the following calculations the basic data given in the above table for Cases *A* and *B*. Against this combination the condensing engines, Cases *B* and *C*, and a high pressure turbine will be considered. For the calculations the following conditions will be

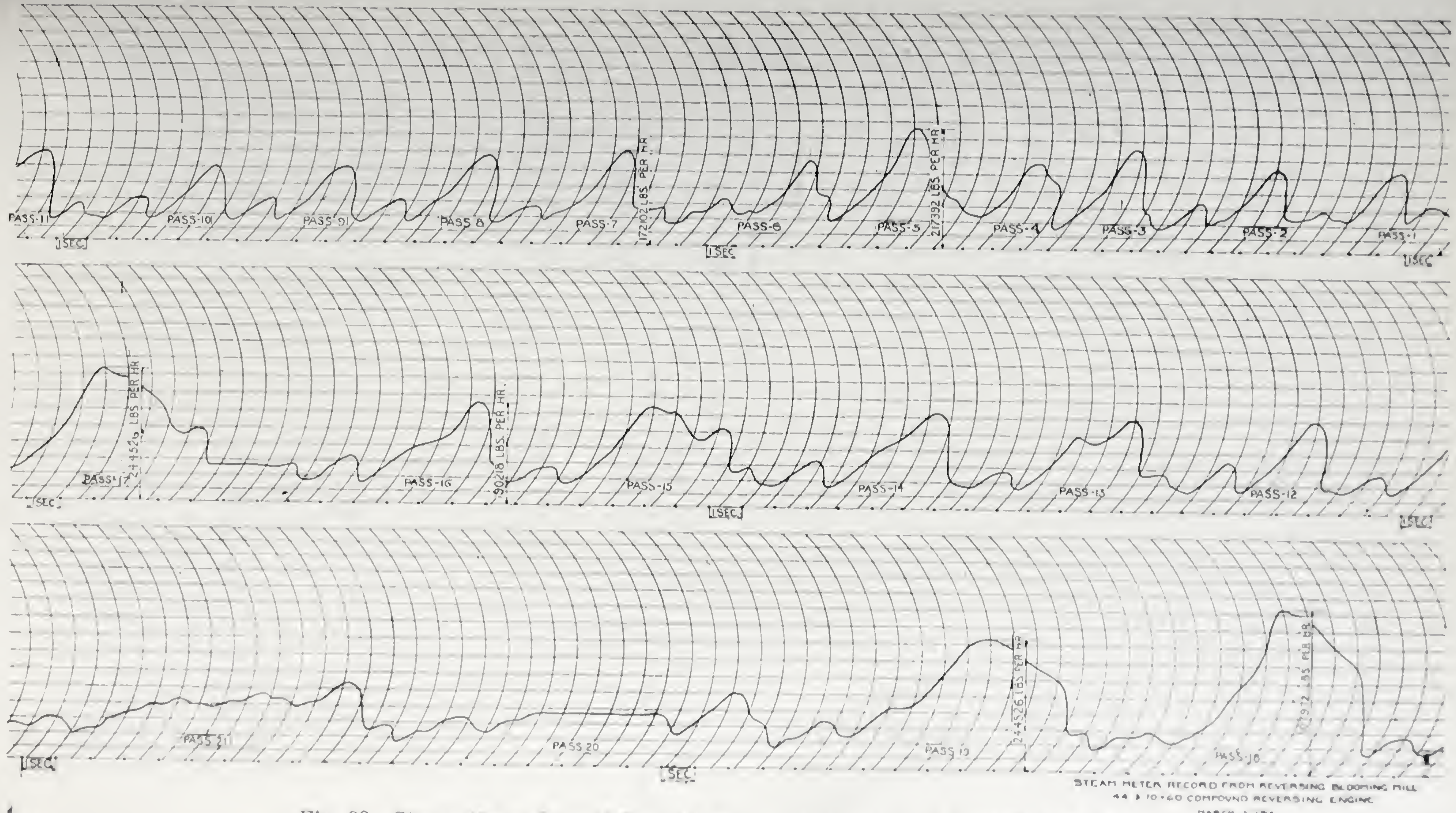

Fig. 22. Steam Meter Record from 44 & 70 × 60 Compound Reversing Engine.

assumed: Market available for the current that can be produced by either type of turbo-generator of 3000 k.w. rated capacity, steam consumption of mixed flow turbine at 28 in. vacuum, 32 lb. per k.w. hour, steam consumption of high pressure turbine at 28 in. vacuum 16 lb. per k.w. hour, exclusive of auxiliaries for both turbines, combined efficiency of turbine and generator 90 percent, cost per ton coal delivered on stokers including all operating and maintenance charges on boiler plant $1.60, water evaporation per pound of coal 7½ lb., working hours per year 6860, average back pressure due to engine exhausting into regenerators 5 lb. gauge—Case *A*, quality of engine exhaust steam 85 percent dry, quality of steam leaving regenerator 100 percent dry, loss due to blowing exhaust steam through regenerator relief valve 10 percent, which must be supplied by the boilers, increase in steam consumption of engine per pound increase in back pressure 2.73 percent.

Example I. Assuming that the engine, Case *A*, is in condition to perform its duty for an extended period of time, would it pay to combine this machine with regenerators and an exhaust steam turbine, or would it be more economical to replace the engine with a compound condensing machine and generate the current that could be produced by the exhaust turbine in a high pressure turbine?

According to above table the engine consumes 45 lb. steam per i.h.p. per hour when the average back pressure is 2-lb. above atmosphere. If the back pressure is increased to an average of 5-lb. due to the regenerators, the steam consumption per i.h.p. hour will be increased to $45 + [45 \times (5 - 2) \times 0.0273] = 49$ lb. The steam consumption of the engine has therefore been increased by 8.2 percent. If the quantity of steam used per hour under these conditions is 100 000 lb. and the exhaust steam is 85 percent dry, the quantity entering the regenerators will be 85 000 lb. If 10 percent of this steam is lost through the regenerator relief valves, the boilers must supply the loss and the amount available for work in the turbine will be 85 000 lb per hour, but the boilers must supply 108 500 lb. per hour. On the 85 000 lb. of dry steam the exhaust turbine will yield an output of

$$\frac{85\,000}{32} = 2660 \text{ k. w.}$$

Hence, on 108 500 lb. per hour supplied by the boilers this combination develops

$$\frac{100\,000}{49} + \frac{2660 \times 1.34}{0.9} = 6000 \text{ i. h. p.}$$

of which 2040 and 3960 have been developed by the engine and turbine respectively. This combination, therefore, will yield one i.h.p. hour on

$$\frac{108\,500}{6000} = 18.1 \text{ lb. steam.}$$

Since the compound condensing engine itself requires only 22.5 lb. steam per i. h. p. hour, the difference in favor of the exhaust bine combination is only 4.4 lb. per i.h.p. hour or 22 percent, and is too small to justify its installation in view of the fact that it has received the benefit of every doubt.

But even under the assumed conditions it will be interesting to continue the calculation in order to see how much money could be saved by the better combination. If the engine, Case *A*, were replaced by the engine, Case *C*, whose steam consumption including condenser auxiliaries is 23.2 lb per i.h.p, hour, the quantity of $2040 \times 23.2 = 47\,330$ lb. steam would be required instead of 108 500 lb. required by the engine and exhaust turbine combination. If the difference, 61 170 lb. per hour, were used in a high pressure turbine there would be developed

$$\frac{61\,170}{16} = 3820 \text{ k. w.}$$

or,

$$\frac{3820 - 2660}{2660} \times 100 = 44\% \text{ more energy.}$$

The economy of this combination would be

$$\frac{108\,500}{2040 + \dfrac{3820 \times 1.34}{0.9}} = 14.0 \text{ lb. steam per i. h. p.}$$

hour as against 18.1 lb. for the former installation, or 30 percent better economy. Since this latter combination develops 3820 — 2660 = 1160 k.w. more than the former, the saving in its favor is.

therefore, $1160 \times 16 = 18\,560$ lb. steam per hour, which according to the conditions of this example, have a yearly value of

$$\frac{18\,560 \times 6860}{7.5 \times 2240} \times 1.60 = \$12\,100$$

Now, if it is assumed that a compound reversing engine together with foundation and connections to condenser cost $95 000, the yearly saving of $12 100 represents an interest of 12.75 percent on the investment. In reality the saving would be greater, probably 15 percent, because the compound condensing engine and high pressure turbine would be entirely free of the losses enumerated above for the simple engine and exhaust turbine. Furthermore, the high pressure turbine could be erected in the central power station while the exhaust turbine would have to be located near the mill engine. Hence, operating costs would be less in the case of the high pressure machine.

In the above calculation the cost of the regenerators is assumed to be equal to that of the mill engine condenser and its auxiliaries, and the cost of the high pressure turbine with its auxiliaries is assumed to be equal to that of the exhaust turbine and its condensing equipment.

In this example the loss of 10 percent due to blowing of regenerator relief valve may, perhaps, be questioned as being too high. This factor will of course vary with the conditions of different plants, according to the quantity of steam exhausted by the engine per unit of time, in other words, it will vary with the size of the regenerator used for a given size of engine. Since no test data are available as to the extent of this loss, the question may or may not be justified. The result of the calculation, however, will not be changed much even if the loss be taken at five percent instead of 10 percent. In this connection it should be noted that in Mr. Leahy's plant, when the slabbing mill engine is operated alone, exhausting 100 000 lb. steam per hour, (whether this is dry or wet is not stated) the turbine at 3000 k.w. load, requiring 96 000 lb. steam per hour, high pressure steam is admitted 4 1-3 percent of the time. The question that arises here is: How much high pressure steam flows into the regenerator during the time specified? Evidently this steam is used to supply deficiencies of a certain nature; caused, perhaps,

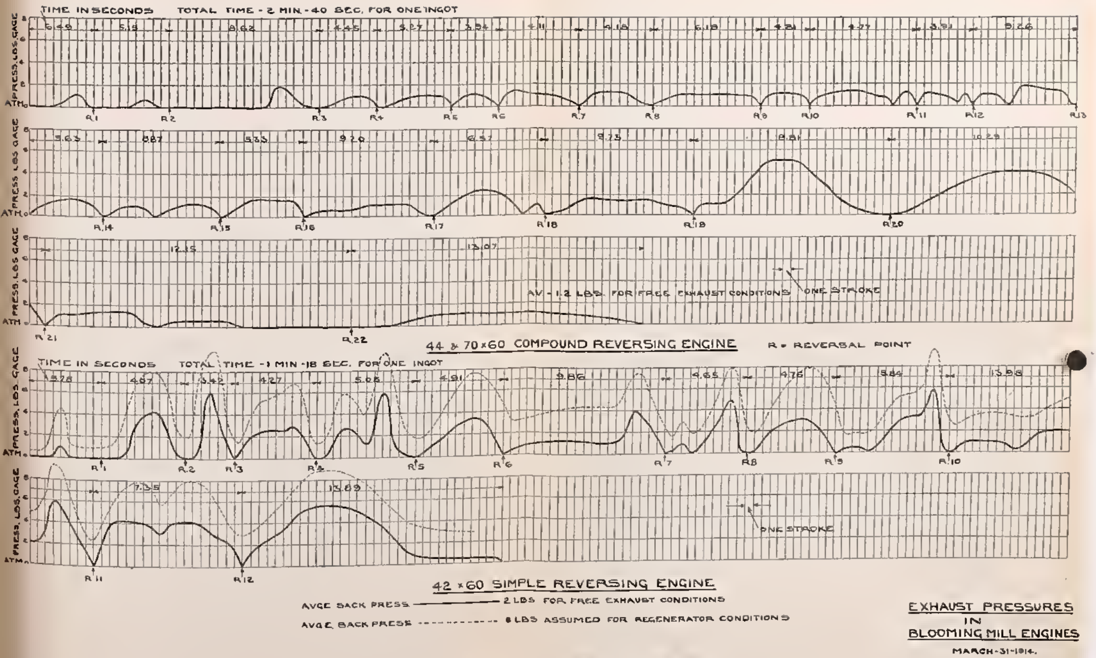

Fig. 23. Exhaust Pressures in Blooming Mill Engines.

by delays in mill operation, etc. If definite information were available on this point, one could judge as to whether or not the above assumption for regenerator loss is high or low.

Hence, the answer to Example I is: It is more economical to replace a simple non-condensing reversing engine with a compound condensing machine and generate electric current in a high pressure turbine, since, in seven to eight years this combination will effect a saving sufficient to pay for the new engine.

Example II: Required the saving that could be effected by operating the engine, Case *B*, condensing, and generating current by a high pressure turbine; as against operating it non-condensing in combination with a mixed flow turbine?

The same assumptions will be made as in the preceding example except that the average back pressure due to the resistance of the regenerators and connections will be taken at 3.5 lb. i.e., 2.3 lb. increase, over free exhaust conditions, and loss through regenerator relief valve at five percent.

In this case the engine at hand is compound, hence no replacement is required, and it is necessary only to provide the condenser and the condenser auxiliaries. This engine when exhausting into the atmosphere requires 48 lb. steam per i.h.p. per hour. If the back pressure due to the regenerators is increased to 3.5 lb. average, the steam consumption per i. h. p. hour will be $48 + 48 \times (3.5 - 1.20) \times 0.0273 = 51$ lb. or an increase of 6.3 percent. If 100 000 pounds per hour are consumed by the engine there will be available at the exhaust 85 000 lb. of dry steam. If five percent of this steam is lost through regenerator relief valves the deficiency must be supplied by the boilers, and the amount available for work in the turbine will be 85 000 lb.; but the boilers must supply 104 250 lb. per hour. The turbine output will again be

$$\frac{85\,000}{32} = 2660 \text{ k. w.}$$

The engine and turbine together will yield

$$\frac{100\,000}{51} + \frac{2660 \times 1.34}{0.9} = 5920 \text{ i. h. p.}$$

of which the engine produced 1960; the turbine 3960. The engine and turbine together produce one horsepower hour on

$$\frac{104\,250}{5920} = 17.61 \text{ lb. steam.}$$

Since this compound engine when operated condensing requires 32 lb. steam per i.h.p. per hour, the above combination has an economy greater by

$$\frac{32 - 17.61}{17.61} \times 100 = 81\%.$$

This figure, however, can only be realized by installing the turbo-generator and its other equipment. As in Example I, it will be found advantageous to run the engine condensing and generate current in a high pressure turbine. Thus, according to above calculation the engine when exhausting into the regenerator produced 1960 i.h.p. Then, amount of steam required when engine is operated condensing is $1960 \times 32 = 67\,720$ lb. per hour, and $104\,250 - 62\,720 = 41\,530$ lb. per hour are available for work in the high pressure turbine which will yield thereon

$$\frac{41\,530}{16} = 2595 \text{ k. w.}$$

which is but 65 k.w. less than the exhaust turbine yields. In this case, therefore, we have equality between the two systems. But, in this case, too, the benefit of every doubt was given the exhaust turbine combination. Everything considered, the condensing engine and high pressure turbine would make a far more flexible and suitable combination for most large steel plants, where central power stations are operated.

Hence, the answer to Example II is: A compound non-condensing reversing engine whose water rate is 51 lb. per i. h. p. per hour, combined with an exhaust turbine, cannot compete with a compound condensing reversing engine whose water rate is 32 lb. per i. h. p. hour, because a high pressure turbine will produce as much energy on the quantity of steam corresponding to the difference in the two water rates of the engine, as the exhaust turbine can on the total steam available from the non-condensing engine.

Example I shows that where a compound condensing re-

versing engine gives a water rate of 23.2 lb. per i.h.p. per hour, there the wasteful non-condensing reversing engine and exhaust turbine would operate at a considerable loss, because, a high pressure turbine will produce so much more energy on the quantity of steam corresponding to the difference in the water rates of the two engines, that a new engine can be paid for by the resulting saving in coal, in a period of seven to eight years.

It follows, therefore, that unless the mill engine conditions are very much more favorable to the combination of regenerators and exhaust turbines, it is not at all apparent how the fabulous savings frequently claimed for such installations can be realized.

Two other points in Mr. Leahy's paper are noteworthy. One being the quality given for the exhaust steam leaving the regenerator (98 percent dry), the other; the method employed for calculating the steam consumption of the turbine, i. e., using the jet condenser as a calorimeter.

Relative to the first point, it can be stated that the chief difficulty in determining the moisture present in steam lies in the fact that the greater part of the water collects and flows along the surface or bottom of the pipe, which makes the collection of a representative sample, by means of nozzles or perforated pipes, extremely difficult.

It may be of interest to mention here that the tests made on a low pressure turbine plant by Dr. Puppe* gave the following results: Throttled high pressure steam 15 percent, exhaust steam 21.8 percent, mixture of both 15.8 percent, measured before regenerators; while 18.5, 24.5 and 19.5 percent respectively, was obtained in the steam leaving the regenerators; i. e., the steam in passing through the regenerators picked up about three percent moisture. In these tests, therefore, the steam was far from being dry.

Relative to the second point, it can be stated that use can be made of the jet condenser as a calorimeter for determining steam consumption of engines and turbines only when the quality of the steam entering the condenser is known. Otherwise, misleading results will be obtained. Since test data from various sources give values for the steam quality leaving the

*Weitere Versuche zur Ermittlung des Kraftbedarfs am Walzwerken.—J. Puppe.

regenerators varying between the limits of 75 and 99 percent dry, it can easily be seen to what extent calculations on the quantity of dry steam available for work in the turbine will be affected if one or the other value be used.

If the method employed by Mr. Leahy be used on jet condensers of engines, the resulting water rates will be abnormally low. For instance; if the jet condenser be employed as a means for determining the steam consumption of an engine, which has dry steam available at the throttle, the condenser heat balance will not give the quality of dry steam that actually entered the cylinder, because part of this steam had condensed in the cylinder and enters the condenser as water. Therefore, to obtain the true steam consumption, the quality of the steam entering the condenser must be known. Since condensation takes place in turbines, although to a lesser extent than in engines, should not the above method be used for calculating the steam consumption of the turbine also?

Mr. F. E. Leahy: The statement by Mr. Smoot that the rate of absorption of this type of regenerator is slow as compared to another type operating under the same conditions may be true. If considered in the abstract the performance might be considered inefficient, but as a regenerator is frequently referred to as a heat fly-wheel whose work is to absorb the excess steam and regenerate it when the demands on the turbine require it, it is evident in this case that any faster rate of absorption by any type of regenerator would be a useless and wasteful expenditure of energy. In this particular installation it would mean the circulation of a large amount of water doing no useful work. As stated before no steam is lost to the atmosphere when either mill is operating alone and when both are operating at the same time no live steam is required.

In Mr. Siebert's discussion the question is raised as to the advisability of installing a low pressure turbine and regenerator in place of a compound condensing engine and high pressure turbine. This is a subject requiring a very comprehensive study in each individual case, and can hardly be solved by the assumption of a number of constants and averages.

To secure the results advanced by Mr. Siebert we would

have to replace three twin simple reversing engines of comparatively recent make and in excellent condition. Admitting the possibility of the change the value of these engines would be only that of scrap, assuming that intending purchasers of units for such service would also be convinced that owing to their extremely uneconomical operation the type was obsolete.

The conditions under which the mills would operate were anticipated as fully as possible together with the available supply of steam and the consumption of the various mill engines, and with this information it was deemed advisable, taking everything into account, to install the present apparatus in place of the units suggested by Mr. Siebert.

The use of a condenser as a calorimeter, to measure the steam consumption, does not present nearly the difficulties in a turbine as it does in the case of an engine. In the case of an engine the flux of steam comes in more or less irregular puffs and the quality is variable due to the initial condensation at various cut offs. The flux of steam from a turbine is more regular and the condensation is uniform as the difference in temperature between the steam and the turbine is nearly constant.

The sampling of the steam was made in accordance with the standard method prescribed by the A. S. M. E., with two different type nozzles and the results obtained were approximately the same.

The various percentages of moisture in the sampled steam at different places as stated by Mr. Siebert are probably correct and only indicate the necessity of corrective methods to secure better results.

CRUCIBLE STEEL: SOME INTERESTING FACTS

By George H. Neilson*

I do not propose to go into the theoretical part of the manufacture of crucible steel, this evening. It is too large a subject to be covered in the time available, besides it would open up a discussion which would have no end. There is such a wide diversity of opinion as to the many chemical and mechanical changes which take place during the working of steel that I would hesitate a long time before plunging into an argument on the subject.

I shall try to show how crucible steel is melted and worked. The subject is not as familiar to most engineers as the bessemer and open hearth processes, so I will confine myself to the practical side of the question and avoid the theoretical as far as possible. The members of our Society, especially the chemists, metallurgists and mechanical engineers, all come in contact with crucible tool steel. To the chemist belongs much of the credit for the great advance made in the quality of steel; without his aid the steel melter would have been at a loss to discover the greater part of his troubles. It is to the chemist we turn when we want to know what is in our steel and how much of certain elements it contains, as without this knowledge, which is of vital importance, we would be working in the dark. The metallurgist has also done much to assist the steel maker as has also the mechanical engineer and the testing laboratories. It has been a case of team work for some years past, instead of the old way of each profession deciding matters for itself. The steel maker has made it possible for the engineer to design shop tools of a capacity undreamed of a few years ago

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Address of Retiring Chairman of the Mechanical Section. Presented before the Section, February 3, and published in the February, 1914, Proceedings.

and he in turn has been benefited by these same tools. There is still room for improvement and with the community of interests working for better steel we may expect decided advances in quality as the years pass.

The tool steel millenium has not yet come so I would caution all users of tool steel not to expect the impossible. Be fair and in case of the failure of a tool do not blame the steel without an investigation. No matter how carefully it is made it is sensitive to treatment and is not fool proof. Do not think that because it is high priced it cannot be damaged and do not go on the supposition that because a blacksmith can make horse shoes, or weld iron, that he is a thoroughly capable tool maker. It is well for the peace of mind of the crucible steel manufacturers that the rule of thumb days have passed in most shops and that the pyrometer has taken the place of the skilled eye which the tool maker inherited from his grandfather. Most of us have run into the overheater of steel who, we are informed, "has been with us for years and is a very capable man, the trouble is certainly not *his* fault." So unless you want a black eye in that shop you must convince the steel "butcher" that he, for once, was off the track. Not an easy or pleasant job. It is the height of folly to buy good steel and then turn it over to cheap labor to work up. It is false economy of the worst kind and is done in a surprisingly large number of places.

Steel, which is carbonized iron, is not only one of the most useful of the metals but is probably one of the first, if not the oldest, of the useful metals. Tubal Cain, who was the first known iron worker, and who probably made steel without knowing what he was making, was born in the seventh generation of Adam. He is described in the fourth chapter of Genesis as an "Instructor of every artificer in brass and iron" and it is only reasonable to suppose that the actual use of iron dates back a few generations farther. How the knowledge of the art was handed down from generation to generation we can only surmise. It was probably for many years known to but few and kept a secret in certain families, as the glass industry was. As the uses to which iron could be put, multi

plied, the workers increased. It was a necessity and, therefore, did not become one of the lost arts. While Damascus, the oldest city in the world, for a time was the leading city in which iron was manufactured, Spain was the leading country as far as the iron industry is concerned. When the Romans conquered Spain they realized the value of the metal and fostered the industry and for many years the implements of war used by the Romans came from Spain. When the Moors drove out the Romans and conquered Spain they also fostered the industry, and it is quite probable that Spanish iron workers fleeing from the Moors introduced the art to other countries. The Catalan Forge got its name from the Spanish Province of Catalonia. The most famous "Iron City" of ancient days was Toledo, noted for the swords made there. The manufacture of Toledo blades, like the Damascus blade, was shrouded in mystery and many are the stories told concerning them. It was said at one time that the great merit of Toledo blades was due to something, just what was not known, in the water in which the blades were hardened. What was probably the cause was an abundance of pure, cold running water which was utilized as a quenching bath. The virtue of clean water was not really appreciated until the art of tempering was given scientific investigation. The mystery of ages, coupled with the stories of the Crusaders and travelers, built up a romance about the old swords which would shrivel if the light of truth could be turned upon it. I doubt if the steel of which these swords were made was as good as steel made for the same purpose today, although the art of tempering was very fully developed. It is said that a Toledo blade could be bent in a circle, kept that way for years, and when released would spring back into its original shape. Swords are still manufactured in Toledo but in a very small way.

That the art of working iron did not become better known for centuries after Tubal's time was due to the very good reason that there were no trade journals or Engineers' Societies to circulate the news. As time went on the knowledge spread and now there is little or no mystery left. It was many centuries, in all probability, before any real attempts were made

to improve the quality of the steel. Chance had more to do with the betterments that were made from time to time than anything else. Who for one minute will suppose that the discovery that steel would harden if, after first being heated, it was cooled in water, was anything but an accident. Is it not more than probable that some careless worker inadvertently dropped the hot piece into the water and thus found a way to immensely increase its usefulness? It was just such chance that lead to the discovery that the overheating of Tungsten steel increased its usefulness as a cutting tool. But chance, while it has played no doubt a very large part, has not been the chief cause of the improvement in steel nor did it lead to the very many uses to which it has been put. The thinking man, the man of trained mind, came into his own and the progress of the crucible steel industry has been along lines laid down by the men who think and not by the rule of thumb. It seems strange perhaps, but it is true, that while the quality of crucible steel has made great strides since the method of melting in crucibles came into use the method itself has changed but little.

The pioneers in crucible melting are said to have been the Chinese, who, used the process many centuries ago. But the art in China never progressed beyond the initial stage. The real father of the crucible steel industry was Daniel Huntsman of Sheffield, England, a clock maker, who found it impossible to get uniform steel from which to make his springs and he hit on the idea of fusing blister steel in a crucible. This was in the latter part of the 18th century and the melting of crucible steel has changed but little since that time. The details have changed somewhat but the actual process is much the same.

The material to be melted is loaded in a crucible, covered with a cap to keep out the gases, and placed in a hot hole and left there until melted. The crucibles have changed, the holes also have been changed in shape and size, and the method of heating is not the same but the process is practically unchanged. Clay crucibles were the first of which we have any definite knowledge. They held about fifty or seventy-five

pounds and lasted but one heat and very often cracked and went to pieces before the steel was melted. Clay crucibles of the present day are much more durable and are extensively used in Europe, but little in this country. They have one decided advantage over the plumbago, or graphite, crucibles in-

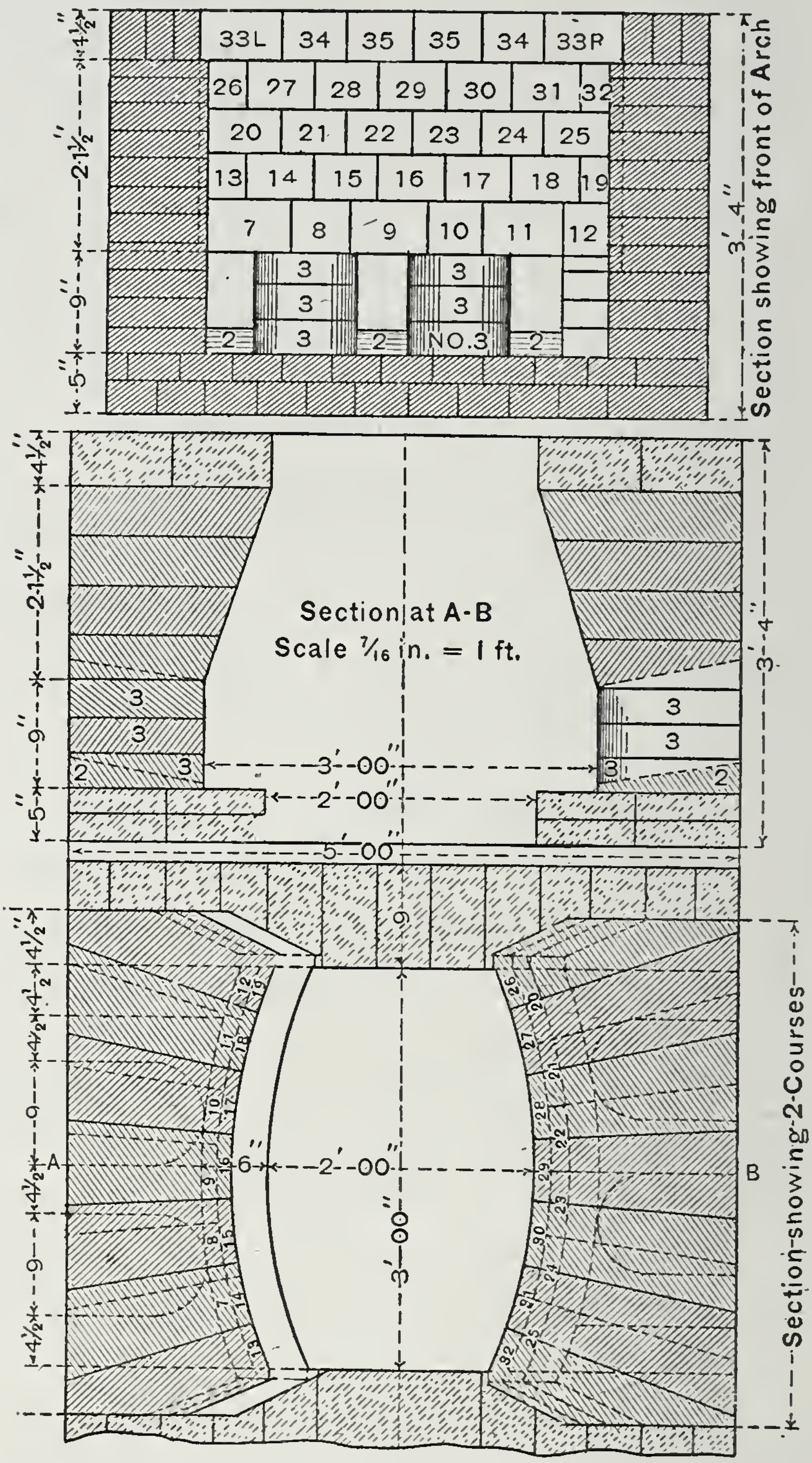

Fig. 1. Detail of Hole in a Crucible Furnace.

asmuch as they do not throw off any carbon during the melting process. The plumbago crucible, which is the most generally used in this country, consists of about equal parts of plumbago and clay. The greater part of the plumbago is imported from Ceylon. These crucibles are capable of with-

standing a very severe heat and can be used a number of times, depending greatly on the nature of the mix and also whether the crucibles are replaced in the furnace before they get cold. The usual practice is to get as many heats as possible from the crucible without letting it cool. As soon as the melted steel is poured out it is re-charged by hand, or by means of a mechanical shaker, and the crucible returned to the melting hole.

Furnace: The modern crucible furnace is of the regenerative type and is heated by gas, generally producer gas, although where natural gas can be obtained it is often used. Natural gas is probably a more costly way to run a furnace but it has many advantages over producer gas. It is easier to regulate, as the flow is constant, which is not the case with producer gas unless a large holder is used. It is free from the poisonous fumes of the producer gas and is much cleaner. I am not in a position to say whether or not it is harder on the crucibles and furnace than producer gas. The capacity of a furnace is spoken of in pots. That is a twenty-four pot, thirty-six pot or sixty pot furnace. That is the number of crucibles the furnace will accommodate at one time. The furnace holes, in which the crucibles are placed, hold six crucibles so a thirty-six pot furnace is one of six holes. The gas enters the holes at the bottom on one side, mixing with the air immediately before entering the melting hole, and passes out at the opposite side and then through checker work to the stack. When the valve is reversed the direction of the flow of the gas is reversed. This is done every fifteen or twenty minutes and in this way the checker work on both sides is kept hot. The gas should not be pulled through the melting hole too rapidly. If it is it will cut the port holes and also cut the crucibles. The gas should fill the melting hole and show a small flame around the covers. This is a sure indication that the gas is getting around the crucible and not pulling across the bottom. The detail of the hole is shown in Fig. 1, and a modern 36-pot furnace in Fig. 2.

Charge or Mix: It has been said that the formation of a mans character is begun generations before he is born. This

Fig. 2. A 36-Pot Furnace.

saying is applicable to crucible steel, in fact it must be "eugenically treated." Its parents should be selected with care, in other words all material used should be of the best. Do not believe the "fakirs" who peddle patent dope the application of which they claim will turn poor steel into good. It cannot be done. You cannot make a silk purse out of a sows ear. You may, of course, help poor material along. It is possible to purify it more or less during the melting process but you cannot make it first class. No heat treatment, no patent nostrums or anything else can take the place of good material to start with.

The basis of good crucible steel is iron and consequently the better the iron the better will be the steel. Therefore, it is vitally necessary that iron low in phosphorus and sulphur be used. As the crucibles generally in use hold from 100 to 125 pounds, the mix or charge is weighed up in lots of that weight and placed in pans, called weigh pans, from which it is transferred to the crucibles. In order to get the exact analysis the weighing must be carefully done, in many cases to the exact ounce. When the crucible is filled it is covered with a cap. This is done to exclude deleterious gases which otherwise would impregnate the steel. When the material to be melted is weighed up the amount of carbon given off by the crucible must be taken into consideration. If this is not done the carbon content of the ingots will run higher than expected. The new pots, as a rule, do not throw off as much carbon as they will the second time used and after the third heat the amount thrown out will be immaterial.

Melting: The length of time necessary to reduce the mix to a molten state varies, depending on the makeup of the mix itself, and will take anywhere from two to five hours. When the steel becomes fluid it is usually good practice to "kill it", or in other words drive out the gases which would otherwise result in blow holes in the ingot. This process of "killing" usually takes from twenty minutes to one hour or longer.

Molds: The molds in general use are known as split angle molds. They are made in two pieces, held together by rings and wedges. One ring at the top and one at the bottom. The

three essential qualities are long life, smooth finish and tight joints. If the inside finish is not smooth the ingot will have a rough surface which may result in defects in the finished bar. If the joints are not tight the hot metal will work through and form a fin on the ingot. This fin will have to be removed, which means added cost. If it is not removed it will work into the steel and cause complications. The smaller molds have the bottoms cast with the sides. The larger molds, seven inch and over, have no bottoms as a rule, the molds being set up on removable

Fig. 3. Cross-sections of Ingots showing Piping.

bottoms. Before the molds are used the general practice is to smoke them with rosin, or some other heavy, greasy, smoke making material. This prevents the ingots from sticking and also makes a smoother surface. The molds should also be warmed before using.

Teeming or Pouring: Teeming is a very important feature and is not merely dumping the hot steel from the crucible into the mold in a haphazard way. In the first place the stream must be steady, if it is stopped and then started again there will be a weak spot in the ingot. The chilling of the metal first poured, however slight, will result in a non-homogeneous mass and the ingot when hammered will break at the point where the stopping of the stream occured. The stream should never be allowed to strike the sides of the mold, if it does it will cut the mold and the result will be rough ingots and in a heat or two put the mold out of commission; also the stream should be started as gently as possible. If it is teemed in without care the metal will splash against the sides of the mold and cause the lower part of the ingot to be rough. This teeming is not as easy as it looks and it takes considerable practice to make a man an expert. The weight lifted is quite considerable, the crucible and the tongs weigh about 60 pounds and the steel about 100 pounds, a total of 160 pounds. When you remember that this weight has to be lifted and held steady so that the steel will flow from the crucible evenly and at a uniform rate the difficulty of doing the work properly can be appreciated. It is not altogether a question of strength, it is knack. Some of our strongest furnace men never learned to teem properly. They had the strength but could not master the art. When a ladle is used, of course, the difficulty of teeming is done away with as the steel can be dumped into the ladle as fast as possible and the teeming is then done from the ladle itself. Both methods have their advantages. It is necessary that the molds be set up straight, or in other words plumb, if they are not the melter is more than likely to teem against the side and also a mold out of plumb is apt to have a bad effect on the steel as it chills. Before the steel is poured out of the crucible the dirt, which has risen to the top should

be removed. This is easily and quickly done by means of a steel rod known as a flux stick, the flux will adhere to it and can be removed without trouble.

Pipe: The worst enemy of the crucible steel melter is piping. Piping is caused by the sides of the ingot cooling faster than the center. The molten steel which comes in contact with the sides of the mold cools much faster than the

Fig. 4. Ingots cast without and with Hot Tops.

center of the ingot. This cooling effect of the mold is felt for as great a distance, approximately, as the mold is thick. In other words a mold 2½ in. thick will have a chilling effect on the hot steel for that depth and the result is that the steel thus affected will separate from the rest and the pipe will form. Of course, this result is greatest at the top of the ingot for the reason that the tendency of the pipe to form lower down is off-set by the metal from the upper part of the ingot filling in the space. The pipe usually continues as shown in the left hand section of Fig. 3; but often, especially if the teeming has been done too rapidly, the pipe appears as shown in the right hand section of Fig. 3. This is the most dangerous form of pipe as it is not easy to detect and remains when the visible pipe has been removed. There is no cure for pipe after it gets into an ingot as it cannot be welded out or worked out and will result in the splitting of the steel when hardened. The most general mode of treating pipe is to use hot tops. A hot top is a brick made of fire clay with a hole through it. The size of brick and hole depending on the size of the ingot cast. The method of handling hot tops is as follows: When the mold has been almost filled the hot top is placed on top of the hot steel in the mold and the hole filled with the melted steel. This plug, as we may call it, settles into the pipe as it develops and also has a tendency to keep the top of the ingot hot and thus lessen the pipe. When the entire mass has cooled the hot top is broken off and the top of the ingot appears as shown in the right hand ingot of Fig. 4, the hot top, which has been broken off, lying on top of the ingot. The result of teeming without a hot top is shown in the left hand ingot of Fig. 4. The hot top, however, does not prevent the formation of small cavities below the main portion of the pipe as shown in Fig. 3. It should be remembered that the hot top brick must be heated to as high a temperature as it will stand before being placed in the ingot. If this is not done the cold brick will chill the steel and destroy the usefulness of the hot top.

To Decrease Pipe: A number of patent molds have been tried but all have been of indifferent success and the added cost has worked against them. There is no doubt that the present

Fig. 5. A 10-inch Bar Mill.

style of mold aids piping and all of us who are makers of high carbon steel are living in hopes that some day someone will discover a mold that will eliminate it, at least to a great extent. Some of the present molds, those for instance which are tapered with the large end up or those that have hot material packed around the top are merely adaptions of the hot top idea.

Topping: When the ingots are cold they are removed from the mold and topped, that is, the top is broken off so that a clean fracture is obtained. This is not a laborious job and two trained toppers can top a large number of ingots during a day's work. A trained eye can tell from the fracture the carbon content of the ingot within 0.05 percent. This is not as difficult as it may seem and anyone with practice can become very efficient. The manganese, phosphorus, sulphur and silicon cannot be determined this way. Neither can the carbon of high speed steel be determined from the fracture.

Working: The process of working the steel after it is made is of great importance and the old rule of thumb days are over. The heating of steel was guessed at and many a good piece of steel was ruined by a worker who inherited his trained eye from his grandfather. Luckily for the steel maker the use of pyrometers is becoming more general every day and guessing at hardening temperatures is rarely done. No steel can be made fool proof and no overheated steel can be made as good as it was before it was overheated. It can, if not too far gone, be restored partially but that is all. High speed steel is as near fool proof as any but even it can be harmed by too much fire. The result of overheating is interesting and I have here some pieces of steel which show its effect. Later I will be glad to show them to any one interested.

Rolling: Rolling, like hammering, must be carefully done if good results are to be expected. The heating should be exact, not guessed at. If the heating is not made to conform to the carbon content of the steel the results will not be satisfactory. Rolling crucible steel is not a tonnage proposition, it cannot be rushed out if good results are expected. It is unlike open hearth steel, where as a general thing "quantity" is the slogan. To illustrate the difference. In reducing a 3-inch square billet

of open hearth to ½-inch round we would have, say fourteen passes through a mill driven at high speed and at the finish a bar of approximately 100 feet in length. With crucible steel, if a ½-inch round, we would have twenty-one passes through a mill driven much slower and a bar about twelve to fourteen feet long, but the extra and slower work means a finished bar much closer to size, planished and free from scale. Fig. 5

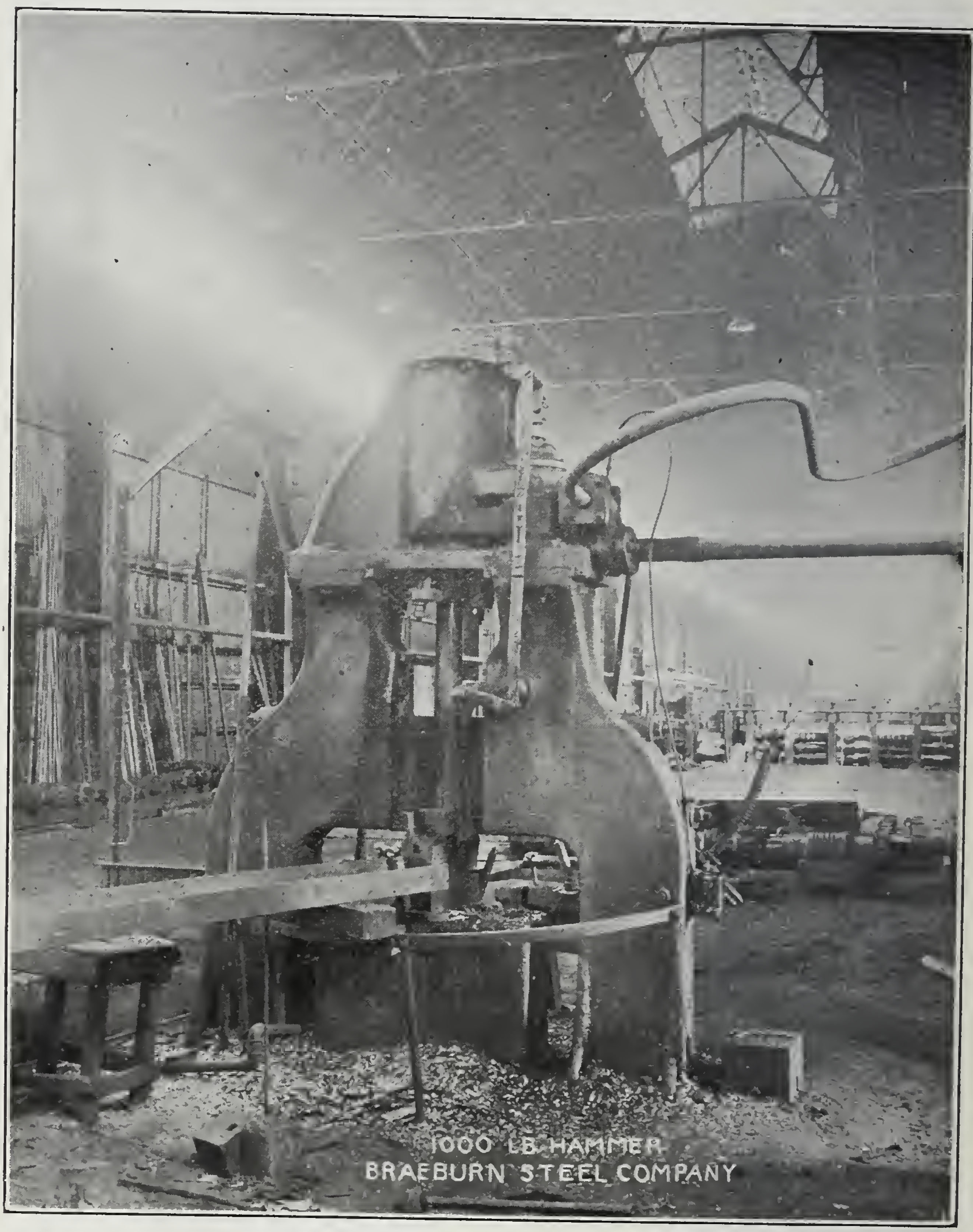

Fig. 6. A 1000-pound Hammer.

shows a modern 10-inch bar mill for rolling high carbon crucible steel.

Hammers: Hammers are of two kinds, single leg and double leg. The single leg hammer has one advantage, the absence of one leg allow the hammerman to work both across and lengthwise on his die which is at times an advantage. This hammer, however, is more difficult to keep steady than the two leg hammer as it has a tendency to spring with the blow of the ram and thus work loose on its foundation. The different size hammers and the size of the work usually done on them is as follows: A 500 lb. hammer, is capable of handling bars ¼-inch up to and including ¾-inch. Fig. 6 shows a 1000 lb. hammer which handles bars from ¾-inch to 1⅝-inch. A 2000 lb. hammer can work bars 1⅝-inch to 3-inch and a three ton hammer, shown in Fig. 7, bars from three to six inch. Of course, smaller or larger sizes than those enumerated can be worked on the various hammers, but the general practice is within the limits given.

The 500-ton steam hydraulic press, shown in Fig. 8, will work high carbon ingots 16 in. square. The press has some advantages over a hammer. It is much easier on the workmen as it is free from shock and jar and for this same reason it does not cause deterioration of furnaces and foundations adjacent to it. It works the steel all the way through and gives it a density which a hammer does not. This is probably due to the fact that pressing the steel causes it to flow while the blow of the hammer is merely local and is not sustained long enough to affect the steel to the center.

Hammering: Hammered steel, that is steel worked into shape under a hammer, must be very carefully handled if the best results are to be obtained. The bar to be hammered must not be overheated, if it is the coarse grain resulting will not respond to the refining influence of the hammer, but it must be soaked or in other words heated through. The hammering must be done intelligently and the blows of the hammer regulated to correspond to the diminishing heat of the bar. It is also important that the work done should not be done under a hammer too heavy or too light for the work. A heavy ham-

mer will rupture the steel and a hammer too light will necessitate too many blows and continued reheating. The weight of a hammer is, in shop parlance, governed by the weight of the ram, piston rod and piston head. For example if the hammer is a six ton hammer then the rod, ram and head weigh six tons. The dies of the hammer are made of cast iron with a chilled surface, ground to a smooth finish. The proper

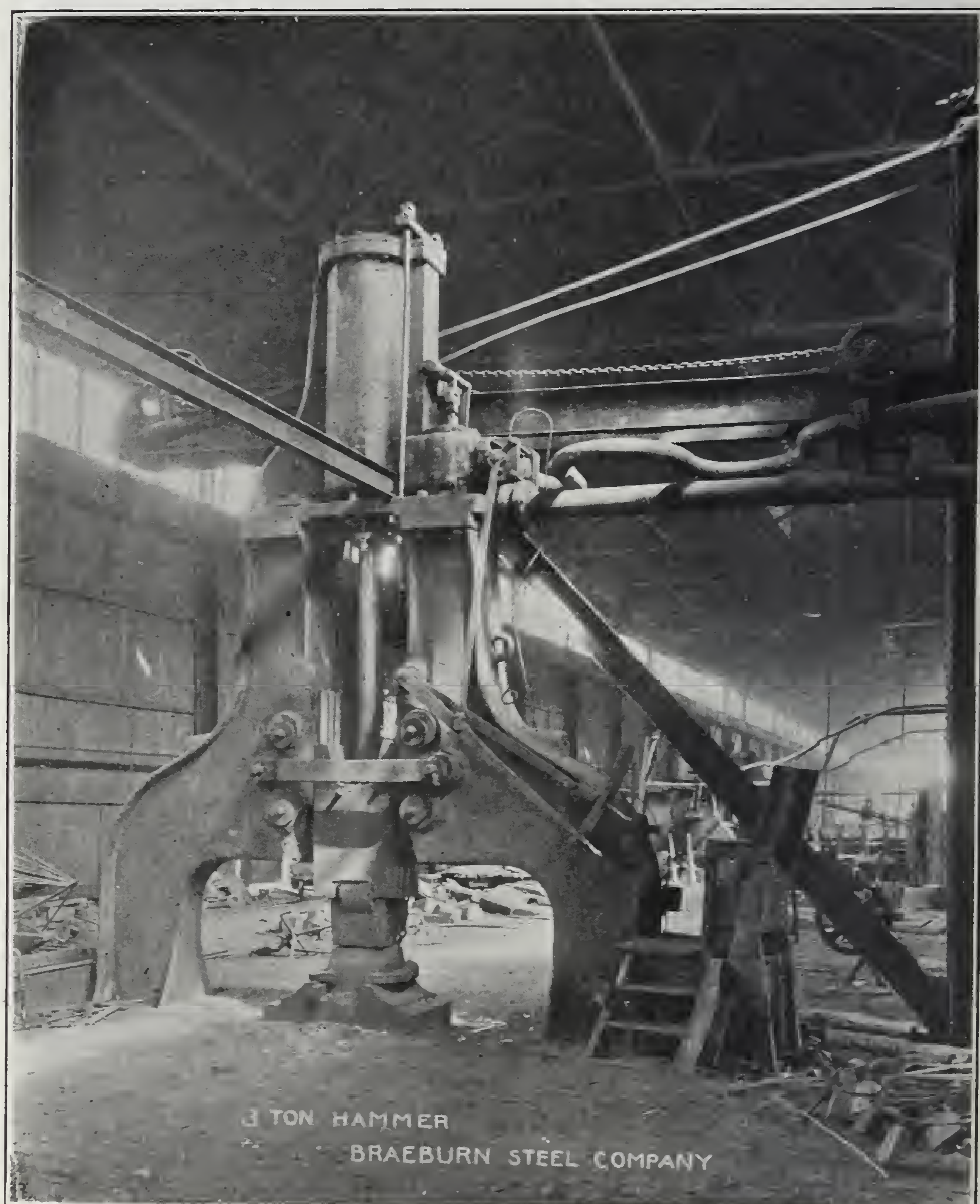

Fig. 7. A 3-Ton Hammer.

grinding of dies is an art, for if the dies are improperly ground it is impossible to get good results, as the bar will be hard to hold and will jump at each blow of the hammer, the result being that the work will not be true to shape or size. Steel dies are sometimes used but they do not take the smooth surface and polish of the iron dies and consequently will not planish the steel as well. The proper hammering of steel is the work of an expert. It cannot be learned in a day and a man to be a good hammerman should have served an apprenticeship under a first class worker. Although hammermen are paid by the ton the work is not rushed out, and quality not quantity should be the watch word. This does not mean that a man does not do a fair days work. It is well known what a days work is on any shape and size but if the work is to be first class as to finish and heat treatment it cannot be rushed. In order to insure good hammermen in Sheffield years ago, the apprenticeship was long and the "Cub", who was not over fourteen years at the time of his being indentured, was bound out to the hammerman for seven years. His wages were what the hammerman chose to give him and the apprentice as a rule lived with his boss and was treated as one of the family. If the hammerman did not play fair the apprentice had recourse to the law and could compel the hammerman to live up to his agreement. It shows what training was thought necessary in order to develop a good workman.

Inspection: All crucible steel should be very thoroughly inspected for defects before shipping. It is much better for all concerned to keep your trouble at home and if there is any doubt as to the soundness of a bar it should be scrapped. It will be cheaper in the end to do this than to take a chance. Inspectors should be given plenty of time and not hurried in their work. All bars should be topped and carefully examined for pipe. Usually pipe is easy to detect but at times pipe shows in the form of a bright spot, no larger than a pin point, known as a "star". It does not indicate the size of the pipe further in the bar and must be followed until no trace of pipe can be found. If the surface of the finished bars show seams they should be filed out if not too deep. If allowed to remain

they will cause trouble especially in a cutting tool, as they will cause cracks when the steel is hardened. If the seams are too deep to file out easily the bar should be scrapped.

Carbon and Alloy Steels: The usefulness of alloy steels was not generally known until a few years ago. Mr. Robert Mushet, who was the pioneer manufacturer of self hardening or air hardening steel, made his discovery in 1868. This steel dif-

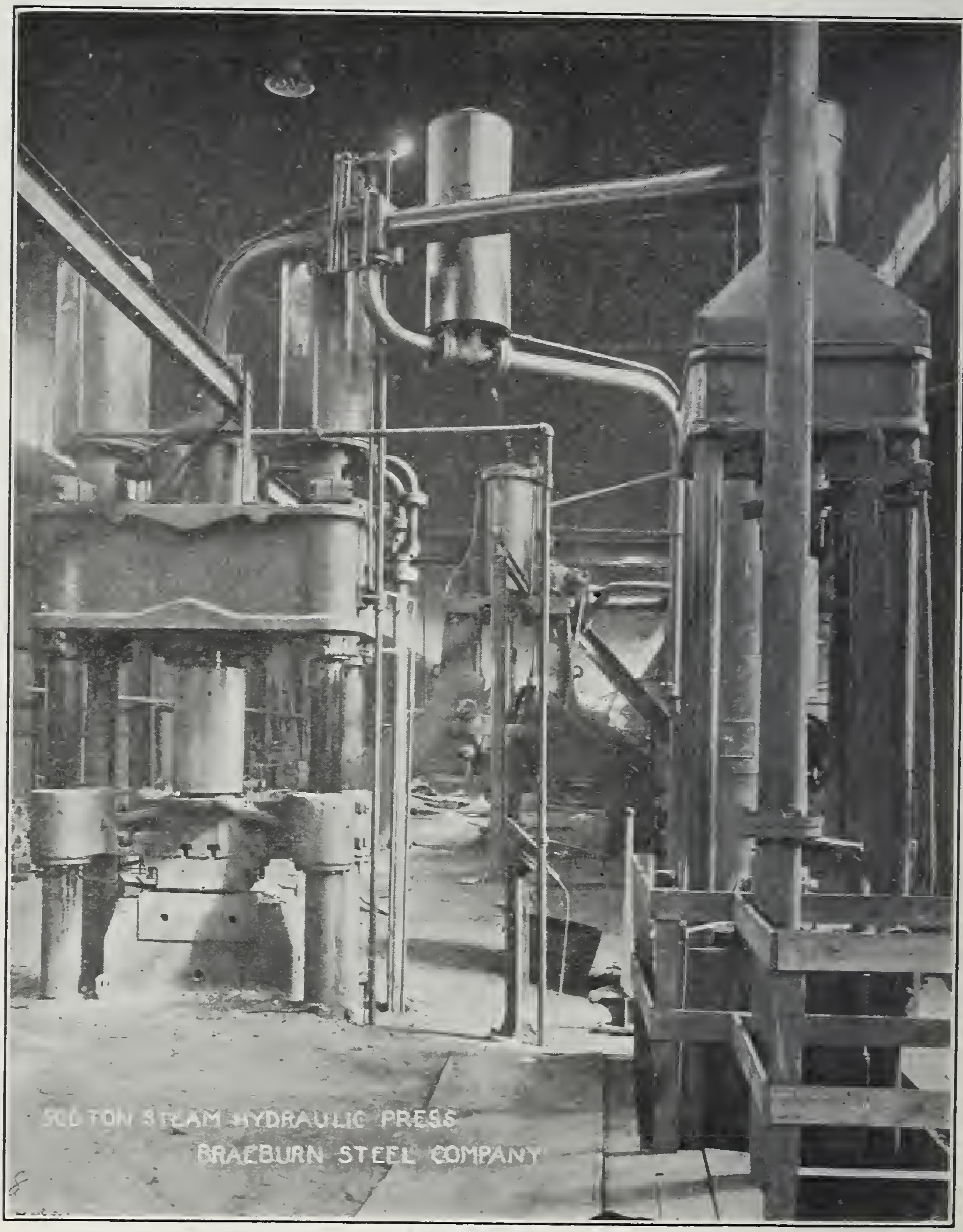

Fig. 8. A 500-Ton Steam Hydraulic Forging Press.

fered from the ordinary or straight carbon steel in that it contained tungsten and that it would harden if heated and then allowed to cool in the air. This Mushet steel had the field to itself until Mr. F. W. Taylor and Mr. Maunsel White, of the Bethlehem Steel Company, discovered high speed steel. This discovery was the result of about twenty-five years of hard work. About 50 000 experiments were made and recorded at an approximate cost of $200 000. It was unfortunate that these gentlemen did not receive the reward their labors surely entitled them to. Their application for a patent was denied and there was a general rush of steel manufacturers into the high speed market, and today there are over one hundred brands of high speed steel. The Taylor-White steel was a Tungsten steel with the addition of Vanadium. These "tungsten-vanadium" high speed steels had the market to themselves until Becker introduced cobalt steel. This steel is a tungsten-vanadium-cobalt steel, which has some valuable properties. Tungsten interested the scientific world some years before Mushet demonstrated its value. We find that in 1783 tungsten was found in the metallic state by D'Elbingar, who presented a memoir on the subject to the Academy of Science at Toulouse. The Duc de Luynes in 1844 published a memoir on the manufacture of cast and damasked steel wherein he points out that tungsten appears in eight of nine analysis given of oriental damasked steel. At the Congress of Miners and Smelters, held in Vienna in 1858, many specimens of tungsten steels were shown. At that time there were many advocates of the good results of tungsten and also many who could see in it no value.

Do not confuse tool steel with crucible steel. This is a very common error and one which should be avoided. Cast steel is also misleading in as much as it often deceives the user. Many of the cheaper grades of tools are made of open hearth steel, which is also a cast steel, so it is seen that tool steel and cast steel do not necessarily mean crucible steel. Another error which is frequently run into is the supposition that the grade of steel depends on its carbon content. This is a mistake and the ordinary grades, I mean by ordinary, straight carbon steel, or in other words non-alloy steel, can be furnished in any reasonable

carbon. Another misapprehension under which many users of steel labor is that the grades of steel can be established by analysis. This is, of course, not the case. I have seen many analyses of open hearth steel which were better than the ordinary grades of crucible steel. If the chemical analysis of steel was all that was necessary to establish its worth the open hearth would have put the crucible out of business long ago.

That the forming of combinations has not caused a decrease in the number of plants engaged in the manufacture of crucible steel is clearly shown in the following table:

Year	No. of Companies	Gross Tons
1889	43	111 500
1892	45	105 000
1894	48	99 000
1896	45	98 700
1898	45	177 000
1901	45	175 000
1904	57	226 610
1908	79	295 385

In 1901, the period of combinations, it shows that there were forty-five companies engaged in the manufacture of crucible steel, while in 1908, there were seventy-nine companies in the business. These figures were taken from the reports of the American Iron & Steel Association.

HOW THE ANCIENTS WOULD HAVE CONTROLLED THE MISSISSIPPI AND ITS TRIBUTARIES

By Sir William Willcocks*

When I went to South Africa for the British Government about ten years ago I remember being asked to address a number of Boer farmers on the question of rust, which had attacked their wheat crops. After describing to them how the Egyptians had for 7000 years sown wheat and leguminous crops in rotation, and at the end of those 7000 years had their land as rich as it was when they first began, while the Boers in 50 years by growing cereals only had made their land so poor they could scarcely get anything to grow on it, I thought I had made an impression on those people; but when I had finished, the chairman said to me, "Now don't talk to us about those exploded old world theories of rotation of crops. We young people have altogether grown out of that." My discourse on that occasion was fruitless. I hope for different things from you.

With your permission I am going to tell you how I think the ancients would have controlled the Mississippi River and the flood problems you have in this country. The problems on the Mississippi are harder than those on the Nile. They are like those on the Euphrates, but the Tigris is more difficult. In Egypt they began reclaiming the delta from upstream downwards. When they had reclaimed a certain part they let the water flow on and reclaimed another, and so on. That was a simple problem. On the Euphrates and Tigris they began from the mouth upwards, as you have done on the Mississippi.

Presented at the regular monthly meeting of the Society May 13, 1914.
*Consulting Engineer, Cairo, Egypt.

I find that the Mississippi is about four times the size of the Nile, seven times the size of the Tigris and twelve times the size of the Euphrates. But size in these questions has nothing to do with difficulty. Indeed, I have always found in any problems I have had to do with, that the bigger the problem the more easy it was to solve. You can see a big problem so clearly and its difficulties lie patent. I have always considered that a thing like the Assuan dam with 180 openings is less of a problem than a dam or a bridge with only one opening, because if one fails, and you have only one, the whole thing fails; but if you have 180 and one or two fail you have still 178. And to bring it home to all of us, I am sure there is not a single married man among us who does not know that Solomon with his 300 wives had a much easier problem than any of us has with his one wife.

The ancients were always very much in earnest with their rivers, far more so than you are here. In this country the lands likely to be inundated by the rivers lie here and there scattered over the face of the country. But in Egypt and ancient Babylonia they had nothing but what was irrigated by their rivers and able to be inundated by them. Everything else was desert. Imagine for an instant the Senators and Representatives in Washington sitting down and looking academically at the question of the Mississippi River levees, if the Capitol itself were located behind one of the levees of the Yazoo basin. Or imagine, as you have here, the Commission which looks after the Mississippi levees taking care to locate itself well up at St. Louis where it is totally out of danger. In Babylonia we should have made them all live behind the worst of their levees, and whatever else they did they would not have had any breaches. I believe you call them crevasses; we call them breaches. Accidents happened on the Mississippi in 1912 and millions of acres were inundated, 4 000 000—the whole of Egypt is only 6 000 000—and little thought was taken of it in this country. In the seventh century of our era a very serious breach occurred in the Tigris levee and the King on that occasion threw 400 engineers and supervisors into the breach.

In 1887 when we had our last very high flood on the Nile

I saw a white haired man going about his work very energetically, and I said to him, "I have never seen an old man as energetic as you". He said, "I am not old, only my hair is gray". I said, "How did it become gray?" He said, "I had charge of the Nile bank in the great breach of 1878. When it occurred the Khedive telegraphed to throw the engineer into the breach. I was that unfortunate man. They did not throw me in because the telegram arrived at evening, and they said they would do it at daybreak. My wife and other members of my family went up on special train to implore the Khedive to let me off. And in the morning I found that my hair had grown absolutely gray".

The Mississippi has been reclaimed, unfortunately for itself, from the mouth up. Louisiana made for itself fields and gardens behind its levees. When the next State farther up the river made its levees and concentrated the flow, it put Louisiana into difficulties. Louisiana raised its levees and then it went easier until the next State up stream started to build levees. And however hard Louisiana works, it can barely keep ahead of the difficulties brought on it.

That is exactly what happens in Noah's flood. There was no Noah's flood in Egypt because in making their river control works they came down with the river. On the Euphrates they traveled up, and it was a very large dike thrown up to protect some upper basin which threw the whole waters of the river on those lower down, which produced the catastrophe known as Noah's flood.

The Mississippi from Cairo to the sea has a length of 1000 miles; in a straight line it is 550 miles, and the width of the valley is about 50 miles. The fall in flood is 320 feet and in low water 270 feet; 1540 miles of levees are along its banks. (In Egypt we have about 900 miles of levees.) The salient points, where the Mississippi bends from side to side, need protection and cover 400 miles. The *natural reservoirs* in the Mississippi valley, which I shall call *basins* to distinguish them from reservoirs which are proposed in the hills, cover a very large area. The St. Francis basin with 4 000 000 acres, the Yazoo with 4 000 000, the Tensas with 3 000 000, and smaller

reservoirs on the sides, bring the total above the Red River to 12 500 000 acres. Down stream from the Red River are 6 500 000 acres. These give altogether 19 000 000 acres of natural reservoirs.

Like all deltaic river valleys, that of the Mississippi is highest near the river bank and slopes away to the hills on either side. In places the water at the bank is 30 ft. higher than at the hills, so that when the water makes a breach it has plenty of land to go over and finds it very easy to get away. Then this river like all deltaic rivers, brings down a great deal of sediment. But the river soon begins to drop this into its bed, and then cuts out from the sides at the bends. Low down in its course nearly the whole of the sediment in the river is that which the river itself is cutting from its own banks.

Allowing six feet of water above the natural bank of the river, which is where the flood of 1882 came to, I calculate that these natural basins, or reservoirs, in the Mississippi valley itself represent about 12 500 000 acres, eight feet deep, or 100-000 000 acre feet. I have put these figures into acre feet because left in cubic feet they run into nine or ten naughts, which represent things we do not understand.

Now if the ancients had had this river, they would have considered these reservoirs as a great asset, and never would have used them or let them be cut by levees until they were quite sure that all the lands below were well protected against inundation. As the first lands to be reclaimed were in Louisiana, the next basin above it is the Tensas. They would have done one of two things. They would have either run the levee down one-half the length of the Tensas, letting the other half be flooded, or they would have taken half the basin in the length of the river and surrounded it with levees, and let the river go around the other half. But they would not have allowed a levee to be put up until the lower ones had been strengthened. Having done that and allowed eight or ten years for the river to adjust itself to the new conditions, they would have gone to the next basin, the Yazoo, and taken half of it and treated it in the same way, previously protecting all the levees below. Then in thirty or forty years they would have gone to the next,

the St. Francis, and taken half and treated it the same way, taking care that everything from there downward was well above the level of any possible flood.

As this operation went on and the waters were cut off from overflowing the basins and kept within the channel, the river would gradually have widened, and may be deepened itself, to meet the new conditions. It would have needed time for that, but you people in this country give nothing time, and the Mississippi River has had no time to do anything in all the operations that have been performed on it. Every time a breach or crevasse occurs in a levee the river down stream for 50 or 60 miles is totally disorganized and all the good done in previous years is thrown away, and the work of making the channel suit its new conditions has to be done again. If it had been done in the way the ancients did, the Mississippi with its 19 000 000 acres of valley, would have had 9 000 000 acres thoroughly reclaimed, and 10 000 000 acres still covered with water in flood time—and being greatly improved with the mud deposited on them.

Acting in a way different from this and letting every one do that which was good in his own eyes, no more than about 4 000 000 acres have been reclaimed, instead of 9 000 000, and much of it indifferently, while the primeval forest covers by far the larger part of the land.

Some may say that this is purely an academic discussion. This is what the ancients would have done. Now the question before us is with the river as it is, supposing the ancient engineers came into this valley as it is today, what would they have done with it? I will first describe what the Mississippi valley is today. If you go down from Cairo, the first basin on the right bank is the St. Francis, with 4 000 000 acres, and it has a levee along almost its entire length. The Yazoo basin of 4 000 000 acres on the left has a levee along almost its entire length. On the right bank the Tensas with 3 000 000 acres has the same; and from the Red River on, both banks have levees past New Orleans to the sea. The small basins are unprotected.

I will lay down a few propositions. Before a basin like the St. Francis is allowed to have a levee, from the end of that

levee downward, calculations should be made and the height of the flood which is going to be artificially produced by that levee, calculated. Then profiles of levees 5 ft. above flood should be put up, 10 ft. wide, every 10 miles all the way down the river, so that every man could see for himself the terrible condition that is coming.

If for example, the Mississippi when in its banks, discharges 1 000 000 cubic feet a second with a velocity of six feet it has worked out for itself, owing to the kind of soil which it has in its valley—and a very poor and bad soil it is to resist the current—it has cut out for itself a channel 5000 ft. wide, and 33 ft. deep. If you put the whole discharge of 2 000 000 feet a second, that passes Cairo, into the stream it would begin by having a depth of 48 ft. or it would rise 15 ft. at once, and with its width still 5000 ft., a velocity of eight feet a second, which is a great increase. It would undoubtedly begin to widen itself. This river has a width which is 150 times its natural depth, so that when you increase its depth by 15 ft. it would want to increase its width by over 2000 ft. But as it increases its width by every ten or eleven feet, the section increases and its depth falls. With water which is wonderful in its adjustment, the stream would adjust itself and in time, if left alone to work out its own salvation, it would become a river about 6500 ft. wide and say 40 ft. deep. And so gradually working in this way you would have got your river only seven feet above its banks in highest flood. But working suddenly and raising suddenly is not engineering.

More important even than the levees as the river sweeps around its bends in its valley are the protective works at its sides. This protection is very well done in this country. Not enough is done to keep pace with the requirements of the river, but what is done is well done. The river instead of tearing down its banks in poor soil, is fixed by matting and stone, as though it was flowing between hills. With these protective works I consider that, if the river in its natural soil can run six feet a second without difficulty, it could take seven feet quite easily if well protected. Now in this country there is no nervousness in raising the water 15 ft. in height and increasing

the velocity from six feet to eight feet, but the extra velocity that would come from these great bends being cut across to make the channel shorter has occasioned extraordinary nervousness. Yet of the two, as I see it, this is the less dangerous. If you increase the velocity from six feet to eight feet that velocity goes clear down the whole river; but if you cut off a bend and increase the velocity at any point you immediately decrease the depth, and this has a wonderful way of adjusting itself. This I have seen for myself. But if you let a cut off take place in a high flood when the river is full and velocity very great, you court an enormous amount of damage. Such things the ancients would have done just after the flood. They would have cut it so that the river would have had eight or nine months to flow under its new conditions and when the next flood came it would not have been very serious, as the river had adjusted itself to its channel. For in all such rivers if you can get the low water supply to flow in any channel, and it is happy in that channel, the flood will follow it without any difficulty. I assume that the salient bends are well protected with mattrasses and stone in your best style. Well burnt, huge bricks of the Babylonian type might be cheaper and better than stone. Great monoliths might be fused in this way.

Where the levee is far away from the mattress protections it might pay to protect only 1000 ft. per mile and let the river bite into its banks between these fixed points. There would be a limit to the biting action and a million dollars might go as far as three million would go if you protected every inch. It is worth trying where the levees are far back.

It is often said that the river Theiss in Hungary was a winding river and they cut off the bends with the result that the water swept down the valley and destroyed the towns and lands lower down. But that was very foolishly done. If instead of beginning at the source and cutting ten or twelve bends off at once, they had begun from the bottom, or mouth of the river, and worked upwards, cutting off one a year, they would have had none of those difficulties, and the citation of this river as a type of that kind of work is not an accurate thing. It was a very badly managed job.

When once a river has accustomed itself to a new channel we know from the river Nile, whose records go back 5000 years, that streams like these raise themselves gradually on their beds very slowly. The Nile valley rises about five inches in 100 years. (The Euphrates has risen about 1½ ft.) So steady is this rise that today if you dig down 24 ft. in the Nile valley and find the foundations of a building you can calculate the number of years at five inches for every 100 years, and you can say B. C. 4000 or 5000, or whatever it may be, this building was built here. And when you dig it up and find the remains you are nearly always right, as the rise has been steady through all the centuries. And although no records of this kind go back in Babylonia, yet the same thing is true, because the foundations of the different buildings in different ages and the different facts recorded all bear witness to this steadiness of rise of the country.

Now I repeat that of all the things you do on the river the first and most important is to protect the cutting of the banks at the salient bends; because when you increase the velocity and change the river from what it was, the thing to do is to fix the points within which it must flow. While it wanders inside those limits, it does not matter what it does.

I have considered this problem only to the Atchafalaya Escape at the Red River because below this there need be no difference. This is a very efficient escape which goes into the Gulf of Mexico and is capable of taking away all the excess waters. I have seen it stated that a river is spoiled by having an escape like that but I think that is a misstatement. If a river is carrying 1 500 000 cu. ft. a second in flood and a breach occurs on one bank and 500 000 cu. ft. goes away and that stream, discharging 1 500 000 cu. ft., suddenly finds itself carrying only 1 000 000 the silt is immediately deposited. But if you have a river capable of carrying 1 500 000 cu. ft. and it suddenly has 2 000 000 cu. ft. put into it, I think it is a wise thing to let that extra 500 000 cu. ft. go down the escape and never enter the channel capable of carrying 1 500 000 cu. ft. I am rather rusty in my Latin and I wish you to correct me if I am wrong, but I think the old Latin phrase is "Natura non facit saltum",

that is "Nature makes no leaps". It is not the deliberate removal of water but the sudden removal by breaches or crevasses which is so harmful.

There is no reservoir that you can find for a river so good as one of these open basins on its banks. The river carries its 1 000 000 cu. ft. per second and it is within its banks. As it rises above 1 000 000 it overflows not in one place, but in a hundred or a thousand or a million, along its entire length of bank. That kind of overflow does not disorganize the stream for it leaves the stream in perfect order and relieves it of an excess of water, so that if you make a levee along one bank of the river and let the other overflow you get a moderately increased scour under control, and not out of control, as it is if levees are built on both sides. The ancients did this always. They built a levee on one bank and when the river was capable of passing the excess of water with one levee they went to work on the other. In this country you have brought both levees up together. If the central government were to say to a State, if you put up your levee where we are not prepared for it we shall give you no help, the State would wait until the levees below were ready, because no one in the valley would move a hand's breadth if they were *sure* that the central authority would give them nothing.

We often hear it stated that things are better today than they were in 1882 when there was one of the greatest floods the Mississippi has known, because there were 442 breaches then and only nine in 1912. But when the water was only of a moderate height above the country, hundreds of breaches would not do as much harm as one breach when it is 12 or 15 ft. above the level of the country. To compare these many breaches with one large breach is very well explained by a fable of Aesop which nicely expresses this situation. The lioness with her one cub went out for a walk and met the fox with her ten cubs. The fox called attention to the great discrepancy in numbers between her cubs and the lioness'. The lioness replied: "My dear woman, *this* is a lion".

Today a new difficulty has begun to appear owing to raising the water on the levees up to 10, 12, 14 or 16 ft. These are

"boils". Where the water is 5 or 6 ft. high on a levee there is no difficulty. But when the water rises, it forces its way through decayed trees buried in the soil under the levees, or through holes bored by crabs, and bursts out on the other side like a geyser. Many breaches in the last overflow they say are attributable to this sudden undermining of the levee which no human being could foresee.

So serious has this become today on the Mississippi that Major Dabney, one of the most experienced of the government engineers in the valley, thinks it may be necessary to build two levees, one behind the other, which will add many millions of dollars to the expense of this work.

I have often heard it said that it seems a pity to allow any land not to be protected by a levee and to leave it open to the floods. But when you consider that out of the 12 500 000 acres in the upper valley, there are only 4 000 000 cultivated today and 8 000 000 are still primeval forest, to go ahead and throw up levees to drown out people down below in order to protect a large area of primeval forest is not doing any good to the country, but rather harm. While if the water was allowed to flow over this land, not as it likes, but within dikes carefully done as it is in Egypt, this land in 20 or 30 years would be so much improved that those people whose land was outside the levees would possibly find themselves better off than those who had been inside the levees. In two years out of three they could get first-class crops on unprotected land; and even in bad years a half crop if they wished.

With these propositions, I shall now go to the question of what the ancients would have done if they found themselves in the valley today. The first thing I think they would have done, judging from what I have seen in Mesopotamia, they would have protected the salient bends. They would have taken care that there was no more eating away of levees. There is no use putting up a very expensive levee here and there and letting the river eat it away. Little progress can be made in this way. You are always spending your money in repairing. And this point is very well insisted on by the government engineers and they carry it out to the limit of the growth of

the stuff of which the mattresses are made. But more than that might be done now with reinforced concrete at your hand. The stuff of which they make mattresses can only grow at a certain rate but this reinforced concrete can be made anywhere and you could keep ahead of the damage that is going on in the valley. The conditions on the lower Mississippi today are very serious, and delay may produce a flood which may be not unlike Noah's flood, some day.

All cut offs would have been allowed by the ancient engineers, according to all their works which I have seen. They would never have spent great sums of money to prevent the river from cutting away inside the channel, because it only takes away money and labor from attending to the main object of keeping the two main levees protected. All money spent inside to keep these bends from cutting across is money thrown away. There is nervousness about this cutting, which is not warranted by anything I have seen. I remember on the Karun River in Persia years ago, the river took an eight mile curve and came back again to the same point, and you could see it four feet higher on one side than on the other. They said whenever that is cut through navigation will be upset for a long time. It cut one day and within a week the river was flowing in its new channel and it was difficult to see how it had run around the eight miles because it seemed to be so happy in this new channel, just as if it had been there from eternity.

The next thing they would do, I think, would be to calculate what the height of a 2 000 000 cu. ft. per second flood with 10 percent added, or 2 200 000 cu. ft. per second, would be in the valley and put up profiles from Cairo down to New Orleans and let everybody see what it meant to have water like that clear down the valley. You have had floods but you do not yet know what it means to have a very high flood without a breach. This country it seems to me has so many problems and big things before it that questions on the lower Mississippi, however serious they may be, are allowed to drift, and yet they reflect on your country and makes it appear just like China, or one of those derelict countries like Mesopotamia.

The next point. Even now though the levees are too long

and everybody knows it, the engineers and the government do not prevent the Yazoo and other basins from extending their levees farther south, or the St. Francis basin from extending its levee and making the difficulties greater than they are at present for those people still farther down the river. I have been a government official for 24 years under strong central governments, and they say to any one "Lengthen that levee even one inch and we will not protect a single inch of it." No more was necessary. No one would dare for a minute to do anything against the will of the government which had all the money in its hands and to whom everybody appeals for help.

Allowing six feet above the bank as not a dangerous height I calculate that we need reservoirs on the Mississippi which represent 34 000 000 acre feet, that is 34 000 000 acres one foot in depth or 1 000 000 acres 34 ft. in depth, or something between them. To meet this we have the left hand small basins and the Yazoo and others open at their ends where we have 6 000 000 acre feet, so we need 28 000 000 acre feet, to be provided by reservoirs. Reservoirs up in the mountains and in the clouds I don't think would affect the Mississippi. They would be so late or so mismanaged that their influence would never reach the place in the nick of time. I am reminded of one of the sayings of Moses to the children of Israel when I hear people saying that if you will only put forests on the hills and put reservoirs up at the heads of the Mississippi River, you will settle the question. This question came up in Moses' time, and he said "Seek not for salvation at the tops of the hills, look not for it at the ends of the valleys, for thy salvation is nigh thee, at thy very doors." We have got the St. Francis basin, far cheaper than any reservoir and one of the cheapest in the world, of which three-quarters would suffice for our needs. Let them protect the upper quarter with levees and let three-quarters of the basin be allowed to be put under water and it would protect the Mississippi River for twenty or thirty years, until the river had widened its channel. In the meantime with transverse dikes from the river to the hills, well adjusted and employed like the ancient Egyptians did theirs, you could let the muddy waters of the Mississippi flow over this basin so that

the lands would be greatly improved, and when the time came for the owners to enter into possession they would be much richer than they are today. If you go across this basin down a range of forty miles, you see only a few wooden shanties and a little clearing and cultivation, and everything else primeval forest. To protect this primeval forest and put the whole river for hundreds of miles into extraordinary difficulty is foolish. If the people don't like it the central government could buy this land. If you make reservoirs in the hills, you will have to buy the land which is to be covered and you will put that out of cultivation forever; while using this basin, far from putting it out of cultivation forever, you would after twenty or thirty years make it many times as rich as it is today, and if the central government purchased it, they could afterwards sell it at a handsome profit.

Nature has succeeded very well in all her efforts because she has a law. It has been well expressed in the lines "So careless of the single life, so careful of the type". In the Mississippi valley you see that everywhere the action of this country has been "So careful of the single life, so careless of the type", and unless a return is made to Nature's wise law no permanent improvement can be assured.

I have already spoken of forests so I need to say little here. There are a few people who have planted oaks, chestnuts, and other fruit bearing trees on a few acres of land that belongs to them and have made money. This is far from saying that every single man who has a square mile of hillside in the country will go at once and plant trees. Ninety-nine out of 100 people are lazy and they are not going to plant the hillsides with trees. So Uncle Sam, the kindest hearted man that ever was known, is called on to plant the forests. Those forests, scores or hundreds of years hence, will help the stream in low supply and ordinary floods but they will have no effect upon it in the heaviest floods, and these are the floods we are concerned with.

If you build reservoirs up in the hills or build a dam across the valley, you must first have expensive openings in it so that the waters may traverse it in order that it may be empty when it is needed. If it is full of water when the rain comes

it will be useless. So that these reservoirs that are provided for flood protection cannot be used for supplying power or helping navigation.

And moreover what is the use of protecting 19 000 000 acres in the Mississippi valley with levees, when only some 4 000 000 are cultivated and the rest is primeval forest and there is neither population nor money to reclaim it.

The people of the Mississippi valley for many and many a year have been rightly nervous and advantage is being taken of this nervousness, for every one with a panacea to go shouting that something must be done at once. Now there is a very well known saying of Lord Palmerston's: "Where you hear a number of people saying that something must be done, something must be done at once, you may be quite sure something very foolish will be done".

I have spoken of the Mississippi. I now come to Pittsburgh. We have here the same problem as on the Mississippi but in a smaller way. The only difference is that on the Mississippi the man on the right bank worries because the man on the left bank puts up a levee. Here you have the satisfaction of knowing that you have created your own difficulties. You have two rivers, the Allegheny and Monongahela, with only 20 000 square miles drainage basin, which really is not a big thing. It is the first small thing I have seen in America. Your rivers are quite ordinary rivers, but they have for short intervals of time most extraordinary floods. The maximum floods they carry are just about what the Tigris and Euphrates carry when they meet. Those rivers have it for months and you have it only for a few hours. But a few hours of water flowing through your house is almost as big a worry as having it for a week.

These two rivers as they come down do not have big reservoirs as the Mississippi has lower down, but they had very fine reservoirs at one time. First of all there were the overflows in the valleys themselves. Then going back in every direction were the side valleys, wide in places and narrow in others. With a river that comes down in high flood for months they would have been of no use, but with a river that comes down only for a few hours or days, the valleys gave ample elbow room,

and by the time the flood got down to the Ohio River, all its force had been spent in filling up these side openings and before it had time to fill them all full the storm had ceased and the flood had passed.

Now what have you done in these years? You have deprived the river of all elbow room. I saw a bridge where the river was 1300 ft. wide and today it is only 650 ft. Nearly half the river has been filled up with factories, with railroads, and with every kind of industrial institution. Then you have erected numerous bridges not with piers one in front of the other, but all irritating the river and holding up the water in every way they can. Now when the river comes, instead of having elbow room as is had in the old days, it finds itself contracted within two solid walls. And if you calculate the height it has come up above the old floods, you will find it has made up in height for the area you yourselves have taken away from it on both sides.

I have heard it said that railroads and factories join in these petitions to Uncle Sam to help them out of their difficulties with reservoirs. The only thing I have been able to compare it to was a case that happened in Europe some years ago. A boy of nineteen murdered his father and mother and when he was up for sentence the judge asked him if he could mention any extenuating circumstances, he said, "I appeal as a poor orphan". These people are very different from those poor people who live in houses that used to be above the flood and now find the water flowing through their drawing rooms when they least expect it.

As far as I can see, you have no more difficult problem here than the city of Rome had where in the course of years the Tiber had risen 10 ft. above the Aventine quarter. They spent many millions of money but they bought all the houses on one side of the river and widened the channel about a third wider than it was, built two walls and raised the banks and now the whole town is protected. It cost a great deal of money but they had no one to appeal to but themselves to do it and they did it. In Pittsburgh too a wall has been proposed. I speak under correction, but when I see the shingle and stuff on which you are

founded I think a wall would not prevent water from coming up from underneath; but it would be easy to raise the streets on both sides of the river and then when the flood came it should not get across it and whatever water seeped through into cellars might be pumped out over the banks. Whether reservoirs are made or whether they are not made, I think this street raising ought to be made on both sides straight away like Rome. If you do make reservoirs and you have a basin of 20 000 square miles, and your reservoirs cut off the water of 10 000 square miles, you still have 10 000 square miles this side of the reservoirs, and if you have a heavy downfall of rain on that it might bring down quite enough to worry you, especially if you had warm rain on top of snow. I think reservoirs ought to be made if they can be made, but whether they are or not the streets should be raised by earth, and if every foot of earth you used were taken from the river you would improve the river to that extent.

The factories and railroads, built low down near the river, must be raised on their own base. I do not know the cost of raising them or whether it is worth while to do it, but considering the millions of dollars they lose owing to the floods, it should be worth doing. No reservoirs in the world could lower the water sufficiently to keep the floods out of them.

For navigation as I see it, there is no better plan than you have, with your weirs and locks, but you have an acid water which eats iron in an extraordinary way and any kind of permanent weir which would not necessitate these iron structures that raise it temporarily would be a great gain. This point was brought to my attention by Captain Fiske. He said "Why couldn't they make bars across the river in places so as to have sufficient length to have no movable apparatus in it and make them of such height that it would suit low water and floods would pass safely over?" This is certainly the correct way for this kind of work, and I had the advice of some of the best men in India when I proposed it for the Tigris. There are many places on your rivers where you could build permanant weirs of a height to suit low water navigation and the high water would flow over very freely. On the Nile we

built permanent structures nine feet above bed level of the stream, which hold up nine feet of water in the summer time, and when the floods come you would not know there was anything in the river at all because when the river rises 30 ft. a 9 ft. obstruction does not count for anything.

Still in an important city like Pittsburgh in addition to whatever you do, something in the way of reservoirs ought to be done if it can be done. In a recent book which you have written on this reservoir question I see that the quantity of water you consider necessary to impound in these reservoirs seems to be in excess of what you need. In all the calculations it has been assumed that when the river rises, its discharge increases up to its maximum gauge. As a matter of fact it does just the opposite. When it is rising fast, it has a great velocity and a great discharge, but when it comes to within seven or eight feet of the top, the velocity has begun to decrease and with it the discharge. On the Tigris, which jumps up and down very much like this, when the river gauge is 15 ft. rising, the discharge is 180 000 cu. ft. a second. When it has risen to 20 ft. and reached its maximum for that rise, its discharge is 120 000 and when it has come down on the other side to 15 ft. the discharge is 90 000 cu. ft. per second. As in all these estimates you have allowed for an increasing discharge and not reduced by half for the falling gauge, a much smaller quantity of water than you have assumed would I think suffice to shelter you from these hours of high flood which produce all the worry.

The difficulty here I think is that the same operation which made your soil very rich in coal has made it very bad for reservoirs. This horizontal sandstone you have here and shale in alternating strata is considered the worst foundation for reservoirs of anything in the world. More accidents to big reservoirs have happened on it than any other. If the strata are inclined at a steep angle and you build your dam on it, it rests on the hard particles and the weak strata are more or less ignored. But if you have horizontal strata and you hold up water with a 150 ft. head, the water works its way through the shale and gradually undermines it; because horizontally it can

do it very easily, and when it reaches a certain point the upper strata settle and the dam collapses.

In your book you show that you spent money on many things but not one penny to find out what your foundations are, and all the rest of it is worth nothing until you are sure of your foundation. You ought to spend some $10 000 for drills and take two of the nearest sites and expose the foundation and see if you can build a dam there. If you find really good foundation, your difficulties will be at an end. There are many sites in Algeria where the French government would give anything to be able to build a reservoir on soil like this. In despair they did build one, but in a few years it was swept away. And your condition is such that if you had a high flood and a reservoir with 150 ft. head on the hills above you and it happened to breach and came on the top of the flood, all the disasters you know of today would be but child's play. And if you had two in the same valley and the upper one burst and came down on the lower one and the two came together you might open the early chapters of Genesis and begin reading about Noah's flood to comfort you. So of all the things that are necessary the first is to be sure. Reservoirs with good foundations up in the clouds are no use. Even if you could open and shut them it would be too slow coming on its way. They must be low down. I never saw such bad looking stuff for reservoirs, and I found that no one had bored down one foot to see. For when you have bad rock it is often necessary to go down 50 or 100 ft. and when the water flows through the dam you have got to make an apron down stream 100 yards wide in order to protect the rock from the action of the water. You have two expenses, one a very expensive dam and the other a very expensive floor down stream to prevent it from being undermined. As far as reservoirs are concerned, if you had granite or steeply inclined crystallized limestone or any of the good rocks in which reservoirs are built, I would back your reservoir project against all the others.. If ever the central government pays for the reservoirs, it would be your certain duty in this town if a reservoir were built near here, to see that the foundation were good. Because rivers with rock suitable for foundation have

been controlled, it does not necessarily follow that you can do the same if you have no suitable rock. You read in the Acts of the Apostles that the seven sons of one Sceva, a Jew, saw St. Paul casting out a devil, so they thought they could, but the man possessed of the devil leaped upon them and left them wounded and half dead. You see their faith was not well founded.

If the reservoirs can be made, or if they cannot, the duty of raising the streets on both sides sufficiently high to protect the lower parts of the town is incumbent on you.

[Discussion of this paper, if forwarded to the office of the Society, will be published in a subsequent issue of the Proceedings.—Editor.]

"THEORY AND PRACTICE IN WRITING BUILDING LAWS"

By John A. Ferguson*

This subject, the time and the place are peculiarly appropriate, not only in themselves, but also in their relation to each other.

The subject, because the drafting of laws regulating the safety of building construction and the occupancy of buildings are among the most important questions before the people today, particularly as nearly every city and state in the union has its commission charged with the duty of drafting new building laws or revising, as much as possible, those in force.

The time, because there is a Commission for the Revision of the Building Laws of the State of Pennsylvania, and when the work of this Commission has been finished it will become necessary for the Commission for the Revision of the Building Laws of this city to resume the work, already started in so capable and broadminded a manner. If the general public and even those entrusted with the passing of city laws could have the time to examine the records of the Commission which has been working for the interests of the City of Pittsburgh for the past two years, they would find that much more has been done and the work has been performed in a much more creditable manner than would appear upon the surface. That which has been done will have a lasting effect on both city and state and has paved the way for future work by formulating the correct principles. Having had the experiences that usually go with the inception of a great work, this Commission has profited and been made more fit to do further work thereby.

The place, because there is no better place for such matters

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to receive intelligent and impartial discussion than before an organization of the engineering profession. Engineers are just coming to realize that they are not only men of stresses and strains or construction records; but, being peculiarly equipped by training as well as by habits of thought, they not only have the right but, since they possess the qualifications distinctly fitting them for careful study and accurate arrangement of information, they are under an obligation to the public to investigate many of these questions of public policy.

Having undertaken the problem of engineering inspection of the safety of all classes of structures that would be benefited by such inspection and having passed upon all such construction within the limits of the City of Pittsburgh during the time he has been in the Bureau of Building Inspection, the writer has become somewhat familiar with what is probably the typical run of structures built in the city, as well as having had an opportunity to study the various kinds of hazard and their relation to the interest and safety of the public and the individual alike. He has had time to realize that the position of any one who undertakes to draw up or enforce a set of laws drafted in the interest of the safety of the public, regulating the housing of the various kinds of enterprises that are conducted in a great city as well as those throughout the surrounding country, which contain a hazard to others than the one directly concerned with the occupation or use of any structure, is not an easy one to perform. On account of all this, the writer has approached the preparation of this paper with some hesitation and no small respect for the task he had set himself.

REASONS WHY BUILDING LAWS ARE NECESSARY

Time was when man had so far progressed beyond the habits and needs of the animals that he was able to come down from the trees, make his home in a nearby cave, knock down with a rude club, the female of his choice, drag her thither and rudely provide for her and his offspring (and by the way, making her do all the work) without violating the health laws or endangering the life or financial interests of his neighbor, through the instability of his towering edifice or of communicating fire

risk. Tuberculosis and other communicable diseases had not been heard of. Neither had the panic of a frightened crowd at public entertainment, or work, caused loss of life through jamming the aisles of the primeval forest to become a menace to his family.

However, as he progressed in the scale of civilization, he became gregarious, his wants become more diversified. He began to manufacture utensils for his service. He discovered how to use and produce fire (right away all the fields of accomplishment, as we know it, were opened to his search and his troubles began), and to construct a rude thatch of poles, thus freeing himself of the need of a naturally warm climate or the neighborhood of a cave in the hillside.

It is not necessary to follow all the way through the development of the structures which man has employed to house himself and protect the product of his art from the inclemency of weather in order to realize the tremendous interest the individual has in the community life, nor is it necessary to specially describe the interdependency for safety of life, limb and proprety, existing today between the individual and the community.

In view of these existing relations, the "community", which was formed earlier in the progress of civilization as a protection against a common enemy from without (usually thieving or killing raids of man or beast) has changed about and is now banded together for the protection of the community and its members from the common enemy within, and this last condition is mainly due to the selfishness of the individual when he feels his own interest is different from that of others. It is here that the general interest of the community must step in and demand of the indivudual what he demands of the community, viz, safety of person and property.

This individuality of interest may chiefly concern: First, those things called monetary, in the world of finance; second, industrial, in the world of labor whether physical or mental; third, domestic, in the world's home or the house in which we work, live and store the products of labor, each with its peculiar

menace to the community life. Our attention will be drawn, especially to the last two in this paper. The general study of "Safety Considerations in Industrial Engineering" has been very ably presented in a paper before this Society, March 19th, and published in the April, 1912, Proceedings, by David S. Beyer. It will only become necessary to refer to that paper for information on this subject, and we can confine our attention to the last item and its peculiar connection with the first. Especial reference being made to the various structures and their safety considerations.

THE LEGAL STATUS OF BUILDING LAWS

In order to thoroughly understand the constitutional power back of building laws it is well to glance at the general plan of our government. The United States is the union under the constitution of the several states for common preservation and protection. The Union and its government having the right only to step in and regulate matters in which the several states are interested, as the making of treaties, declaring war and the interstate relations. The United States has power to enact only such laws as are directly or by implication given to it by the constitution.

The states in general have the right to enact all such laws as are not specifically prohibited either by state or national constitution. However, the states cannot enact so-called "special legislation" regulating county, village or township affairs, incorporating cities or villages, or changing or amending the charter of any town or village, or regulating the jurisdiction of police magistrates, etc.

The state can consequently enact laws of a uniform character throughout the state, but must delegate to the municipality, etc., the right to enact such legislaion, through the proper channels, as may be required by purely local conditions.

Among the various doctrines as to the right to enact or execute building laws is the police power. This power is not defined by law as it would tend to lessen its effectiveness. Owing to this lack of definition the legislature and those executives that are entrusted with the care of public safety *can* exercise

some broad powers. All regulation by legislation or by departmental rule, governing the public health, safety and morals is based upon this police power. It is about the broadest power possessed by the government.

The right of eminent domain is said to cover the right of the state to enter private property and suppress or change its use where obnoxious to the public health, safety or morals. If property is not taken in this case there can be no claim for compensation. This last is invoked when wrecking a structure to prevent the spread of a conflagration, when an owner refuses to raze a dangerous structure, or when entering a property for the purpose of inspection.

Whenever a series of acts become a public nuisance the aggrieved parties have the legal right to abate it. However, the necessary steps must be taken through the properly constituted authorities.

It has been a maxim of common law and a fundamental principle with respect to real as well as personal property ever since the days of the Roman law that a person has the right to use his own property only to the extent that he does not thereby injure that of his neighbor. Civilization imposes burdens. However, it distributes the load. Each one is doing his share in carrying the economic loss due to the careless habits of others. This loss is distributed to each through the ordinary channels of business whether we realize it or not. It will be seen that the public has a very definite and real right to take the necessary steps to prevent, as far as possible, the economic loss as well as the loss of health, life and morals of individuals. To accomplish this it is necessary to carefully regulate fire prevention and protection, to see that sufficient exits are provided to prevent loss of life in panic, to provide against overcrowding in tenements, sweatshops or places of public assembly, to conserve the public health and morals, and to so regulate the business relations of individuals as to conserve equal rights and justice to all in the making and enforcing of laws regulating the construction and occupation of buildings.

Since the state legislature cannot pass special legislation to

make state laws different in one section from those of another. all legislation passed should be such that it will be proper to enforce it anywhere in the state, leaving to the local governments the right to add the laws required to provide for the purely local conditions.[1] In order to conform with this, the local government should have the power to organize its own enforcing body, the cost of which should then be chargeable to the city or town and the personnel be appointed from those in the locality and familiar with its peculiar needs. No part of such cost should be placed on the state to be distributed over the territory less able to pay for it, and not benefiting therefrom. Every person in such an organization should be answerable to the body which has the appointing power for the proper conduct of their work. Reports of as general or detailed a character as desirable should be made to the state.

An additional reason for such arrangement can now be brought forward. It is based upon the fact that any body organized for the purpose of transacting business will completely fail to achieve its proper effectiveness if that body is extended too far and becomes unwieldy or over-organized, or if its personnel is chosen from among those whose interest is foreign to the work which is to be performed. This would become especially true in the case of localities where a large amount of building work is done.

Thus it is easily seen that, for proper effectiveness, any locality large enough to afford its own police officers should choose them from among its own members and provide for their discipline free from any but the most general supervision by the state. Personal supervision, such as giving state officers the right to remove a city officer without formality of preferring civil service charges could result in wholly demoralizing influences. Since this is not the case with the purely police officers it should be apparent to even the layman that the case of those charged with the enforcement of building laws is exactly the same as any police officer.

[1]In other words the state law should be broad, covering general conditions throughout the state, and sufficiently specific to take care of requirements other than those of cities, which are necessarily more severe due to increased hazard occasioned by density of population.

GENERAL REQUIREMENTS

On this point there will be found the greatest difference of opinion imaginable. The writer has heard as many different opinions expressed on the proper way to attack this part of the problem as there have been persons expressing them. So if in tonight's discussion many points are raised on this portion of the paper do not lay it altogether to the incorrectness of its contents.

As a result of the great diversity of opinion about what should and what should not be incorporated in building laws (and this diversity seems to be the result of the fact that there is so little widespread, exact knowledge of the subject) it is well to outline, at the beginning, the kind of men who should be chosen to do this work and the attitude of mind with which they should approach the work set before them. In the first place, it should be plainly understood that only those who are known by general reputation to be the best technicians in their various lines as well as the broadest minded in the community, should be invited to assist in so exacting a piece of work. Then they should approach their task as if every policy, every general requirement or detail were to be arranged from an entirely new field, and must be studied out with a broad view of the needs of the public rather than the especial hobbies of any individual, keeping in mind always that the law is only to conserve to the general public, life, health and property and not in any way to so restrain the individual that he cannot exercise the greatest amount of initiative possible in the conduct of his business.

Members of a commission for the revision of building laws should be so chosen as to have at least one representative for every business interest which would be largely affected by the laws it is proposed to formulate, and too much stress cannot be laid upon the fact that only the best and broadest minded from each interest represented should be chosen as members of such a commission. If there are distinct divisions in some of these interests, then the commission should have the power to employ men especially versed along such lines to report upon them, and to draft provisional matter in the proper form for the commission to review and take such action as they see fit.

A commission should have power to procure evidence, to call before it those having special information upon any subject and to employ others, having experience, to advise them and even to provide outlines or briefs showing what should be in the laws. The best results always seem to have come from following the method of having one man cover the ground and others to carefully check him up. A commission should have the power to subpoena witnesses, and those especially interested, to testify under oath, and to hear the cases of the various interests, allowing them to submit proposed drafts of the various portions of the building law affected in each case.

Examinations of the various methods of organization and the results of the work of the various commissions recently appointed, has shown that it is almost always advisable to invite various local technical and public organizations look over the proposed laws and add their suggestions and to cooperate with the commission by furnishing sets of standard practice or any information of which they are in possession. Since everyone knows it is practically impossible for anyone to place his work in perfect shape it is well to allow committees from technical societies to suggest additions, omissions or changes that should be made to the laws after they are in the proposed form. Having all matters threshed out in this manner effectually forestalls the claim that partiality had been used, or special interests influenced the result, and the desire to rush to the halls of legislative fame to find relief from conditions by amendment. This last can have and has had quite a vicious result at times.

Right here is where those in responsible charge in the building inspector's end of the work can, by using the proper amount of backbone, forestall to a great extent, many such things by opposing all vicious changes with vigor. It would be possible to gain much strength along this line, by providing a permanent Board of Appeal, selected by appointment from among representative men of the broadest ability in the community, and requiring all such matters to pass through their hands before the law-making body would be called upon to act. If the building inspector had then the power to make rulings which would not become operative until endorsed by the Board of Appeals,

on all those matters so difficult to cover in the body of a building law but which are bound to come up, many matters now settled by the building inspector would either be proven incorrect and the decision changed, or held to be correct and enforced. Such a Board of Appeal would then be a kind of permanent commission for the revision of building laws. It should also act in the usual manner to decide questions when the interested parties feel that the Building Inspector has not arrived at the correct decision. As is usual, where professional services are performed the members of this board should be paid for their time according to the work they do.

As it will now be seen, those who are invited to perform the work of writing building laws are not taking the place of the law-makers. Such matters are not laws until they have passed the legislative body, either municipal or state, as provided by statute, the status of a commission being that of the professional man engaged to perform work which the layman legislator finds himself poorly prepared to do. In view of the vast amount of work to be done in all cases and the fact that those who are fitted to do the work have prepared themselves at great expense of both money and time in order to sell their services and special knowledge, and are always under the necessity of earning a living, it is not right for the public to demand their time without fair return commensurate with the service performed. The lot of the member of such a commission is a strenuous and thankless one and the general public never fully appreciates the immense amount of work that has been done. If the matter of a proper compensation for doing this work were more carefully looked into it certainly would be found to have a tendency to remove the complaint about delay by removing the temptation to delay. Compensation in the form of a lump sum would be found to have a beneficial effect. Members of a commission should be chosen from among those leading the technical and other societies. The following professions and vocations should be represented:

Architects	2	to be selected.	
Structural Engineer	1	"	" "
Sanitary Engineer	1	"	" "
General Contractor	1	"	" "
Real Estate Interests	1	"	" "
Physician	1	"	" "
Lawyer	1	"	" "

It being understood that the chairman of any body of men is the one upon whom the bulk of the work is thrown, the chairman should be chosen from one of the two professions more deeply interested, viz. Engineering or Architecture. The chairman of any committee should be the man representing the specialty covered by the work of that committee. The physician should be chosen from among those most active in welfare work. The general qualifications that should be possessed by the personnel of a commission have been explained earlier in this paper but one added comment will not be out of place here, and no better statement of the actual conditions can be made than by quoting from a letter written by Mr. C. H. Blackall, architect, of Boston and a member of the Building Law Commission for that city, to Mr. Edward Stotz, chairman of our own Commission, dated May 1, 1911, as follows: "As a result of my experience, I feel quite convinced that the only way to prepare an adequate building law is to place it entirely in the hands of technical experts including one liberal minded and clear headed lawyer who can give it the necessary legal term. It is simply hopeless if laymen, as such, are to take a hand in its shaping."

The workings of such a commission will be more efficient if there is as little "red tape" as possible carried into its proceedings. The body of men performing the work should be small, but composed of men possessing sufficient mental caliber to perform the work in a big hearted, broad minded manner. That a body of laymen attempting to draft building laws after listening to the testimony of technical men is bound to produce a very unsatisfactory result will be found to be true and has been found thus in one notable case, that of the "Commission

of Chicago", a councilmanic committee. It was necessary, after the committe had gone over the work twice, to then refer matters to a body of technical men who finally did the work. A short quotation from a letter written by Messrs. Pond and Pond, architects, of Chicago, who worked on the final draft of this ordinance, to Mr. Edward Stotz, dated May 3, 1911, is as follows: "A small committee with public hearings and discussions is in a better position to do an intelligent, coherent and thoroughly co-ordinated piece of work than a large committee and with less expense to the people who actually do the work."

Since all who worked on this law donated their services, the cost of doing the work was nominal. Incidentals alone were chargeable to the account. Listen to Mr. Pond's own idea expressed afterwards: "The method was wrong, the experts should have been paid for their work."

The Commission which wrote a new building law for Massachusetts was paid for its work, the chairman receiving $2000 and the other members $1000 each. The total expense was $14 000. Information as to the professions represented on this body did not come to hand. I should judge that there were no engineers, as such, in the Commission, as there is not a very extended description of the construction requirements. In the judgment of the writer, no building law is complete without this, or even as effective as it should be. Good construction will go far toward eliminating many of the evils of the other conditions.

The Commission which is now engaged in writing a new state building law for Ohio, as described to the writer by Mr. Fred. W. Elliott, consulting architect, of Columbus, Ohio, is composed of the State Factory Inspector, State Fire Marshall, and the Secretary of the State Board of Health, none of whom receive any compensation as members of the Commission. The Commission employs a consulting architect and a stenographer and maintains an office.

Co-operation was invited and secured through the assistance of the various business and professional organizations of the state. A committee of seven was chosen a year ago to represent all of these. The Commission and Committee are working har-

moniously together, differences are being amicably settled and results accomplished and the result will be a "Code", the cost to date has been $11 473 and four parts of the law have been completed, viz: "Theatres, Assembly Halls, Standard Devices, and Sanitation. In consequence, Ohio bids fair to have a "Code."

A tentative draft of the administrative section for the Ohio "Code" provides for a permanent Board of Appeal to decide all questions of interpretation, application and enforcement of the "Code" and to decide when a different fixture or device, etc., complies with the purpose and intent of the "Code" and to prepare amandments from time to time as may become necessary. In addition to this, the writer would like to add to the above that such Board should be made a body capable of approving all Bureau rulings. Such rulings to cover the thousand and one details coming up from day to day in the administrative work of the building inspector and should never go into the drafting of the law as conditions are constantly changing. In this way the building law would have the proper leeway and flexibility to change with the times so as not to actually hinder progress in building construction as some clauses in our own act have a tendency to do at the present time. And a further result would be a proper check on the work of the building inspector to prevent mistakes and to uphold him where his experience teaches that he must or must not yield to the pleadings of individuals working for their own selfish interests.

It will not be necessary to review in all its detail the work of revising the building law of the City of New York. How they labored for years, and how the financial interests of building supply concerns were often considered, to the detriment of the owner of a proposed building. How it was charged that material supply interests fought for advantages, some winning, some losing; some demanding unfair, costly and needless specifications, and how some of those who desired fair and honorable regulation of their work were not considered. The work has been undergoing continual revision and amendment ever since. The total cost of this work being $350 000. Listen to the comment of one who knew about it at the time: "Our $350 000 was

spent in attempt to revise the New York Building Code unsuccessfully'', as made by Mr. Grosvenor Atterbury to Mr. Edward Stotz, April 3, 1911.

The City of Cleveland is at the present time, revising a building code passed some time ago. The Building Inspector, Mr. Allen, is doing the work, which is then reviewed by a committee of experts selected from the various local societies. Results are not complete, but it promises to be a creditable piece or work. The cost will be nominal.

It will be seen that the cost of doing the work is not a criterion of its excellence. Excellence depends upon the personnel of the workers. The writer cannot see any more convincing arguments for careful selection of men with good judgment and technical training than the facts just enumerated.

In our own City and State there are commissions which have been doing good work. The appointment of a Commission for the Revision of the Building Laws of Pittsburgh had been agitated for many years before it finally became a fact, and composed of men, most of whom were the best representatives of their respective callings.

In the summeer of 1909 a joint conference was called by the Pittsburgh Chapter of The American Institute of Architects and representatives of the Engineers' Society of Western Pennsylvania, Chamber of Commerce, Master Builders Association, Board of Fire Underwriters of Allegheny County, Builders Exchange League, Allegheny County Bar Association, Civic Club of Allegheny County, Electrical Contractors Association, Civic Commission, Pittsburgh Board of Trade and Master Plumbers Association. A Commission was by them deemed a necessity. Pursuant to this the matter was taken up with the Mayor, and Council created a Commission by Resolution No. 170, Jan. 31, 1910. This Commission was given a small appropriation, was to act without compensation and immediately began wark. A collection of the building laws of ten principal cities was procured, together with the Code of the National Board of Fire Underwriters. Thirty-five separate parts or divisions giving the general gist of these documents were collated on each different kind of construction, and studies for procedure made.

This material covered about 1700 pages of typewritten matter. This document is one of the present possessions of the State Commission for the Revision of Building Laws. Early in the work of the Pittsburgh Commission it was found that it would be impossible to do what was necessary to bring the laws of this city up to the standard required by modern building progress and living conditions without serious conflict with the state laws. A resume of the objections to the laws then in force as set forth in a communication to the Mayor as a result of the joint conference just mentioned, is here quoted in part:

"I. In the present law there is found no provision in *'Party Walls'* for the use of steel or reinforced concrete construction.

II. *Classification of buildings* is vague and incomplete. In many instances permits the owner to designate the class to which his building belongs.

III. *Fire proofing*: The present law is vague and inconsistent with the best modern practice.

IV. *Definitions*: The lack of clearness in the meaning of certain words and expressions gives opportunities to violate the real intent of the existing law.

V. *Foundations*: The use of other materials than brick and stone is not provided for.

VI. *Elevators and Enclosures*: The law in regard to the materials of the inclosures, installation and inspection of elevators is not up to the best modern practice.

VII. *Stairs, Corridors, Exits and Fire Escapes*: The regulations concerning some of the same apply to a limited number of buildings only and should be extended to include all excepting those now specifically described.

VIII. *Inadequacy*: The lack of clearness and the meagerness of the code, together with the great discretionary powers vested by it in the inspector results in undeserved loss to the building public by reason of inability to learn the law prior to the taking out of a permit. This results in the inspector, intended as an executive officer only, making up the laws from day to day and the changing of the laws, to some extent, with each change in the inspector. All of these things are an unnecessary burden to the entire public and particularly to the Bureau of Building Inspection.

Our knowledge of the inadequacy of the laws has resulted in a concerted movement, looking to the amelioration of the existing conditions."

Accordingly the Pittsburgh Commission took up the advisability of state legislation with the Governor. After several conferences, in which the Commission were assisted and supported by statewide organizations his consent was obtained and after considerable work a measure was prepared by the Pittsburgh Commission and presented to the legislature. The measure was passed organizing a State Commission and appropriating $6000 for its work. Again a building laws Commission working without compensation. This State Commission is working to completely revise and rewrite the state enactments down to date. That they have a large task goes without question as all familiar with the matter are aware.

Since then, after considerable work and worry the Pittsburgh Commission has succeeded in having prepared three ordinances, which have become law. The first one to be completed was the Ordinance Regulating the Construction of Hollow Block and Terra Cotta Walls of Buildings. The next to be completed was the Ordinance Authorizing and Regulating the Erection of Steel Frame Structures, and the Use of Iron and Steel in the Construction of Buildings which passed Council June 24, and was signed by the Mayor June 30th, 1913. And the next was the Ordinance Authorizing and Regulating the Use of Concrete and Reinforced Concrete in the Construction of Buildings, which passed Council Dec. 4, and was signed by the Mayor Dec. 11, 1913.

Other ordinances in the course of preparation are, Strength of Materials and Fire Protection and Prevention. The ordinance covering steel construction, while carefully and correctly written, did not stir the interest of the public as much as did the preparation of the concrete ordinance. I have heard many comments on the form of both and copies of the concrete ordinance are constantly in demand all over the country. It has proven an excellent work. While not all can be pleased by such a law, all admit that it is fair and equitable. By the exercise of common sense in regard to all special cases, patented systems and the like, this ordinance promises relief from past conditions. Only one thing further is needed, a small engineering inspection force to assist in administration of the laws. At

present one lone man is charged with keeping track of both inside and outside work in all the details. That much outside work goes entirely unseen is the certain result. It has seemed more important to attend to the matter of proper design and specifications in the office, first, and construction work afterward, as much as possible in the time left for it.

Matters arise daily in the engineering end of the work that require: First, very careful study before laying down a method of procedure which will be correct from the standpoint of the best engineering practice; and, second, as fair and open treatment to the interested parties as is possible. Equity is maintained among the various construction interests and should and does receive a great deal of studious thought.

In the writer's judgment, the best building law is one which is built up around a careful and comprehensive series of definitions which classify all building requirements for health, public safety, public morals and fire protection. Such a series of definitions should be the whole attitude of the law, not the idea of restriction or the attitude of "thou shalt not." Each use to which a building is to be put, or may be put, should be defined and classified according to the hazard to be overcome and the minimum requirements set forth in clear, readable, everyday English.

Definitions classifying the different methods of construction, as to fire protection, sanitary and safe construction should come first. Definitions grading the various structures according to their intended use and occupancy should come next. These requirements should be followed by a series of definitions and specifications governing the use of all building materials, taking each in turn and completing the requirements for each before undertaking the next one. A general method of construction governing a peculiar combination or use of building materials should be treated under a separate heading, viz: Steel or Reinforced Concrete Structural Framing, Use of Terra Cotta Tile Construction, Electric Wiring, Plumbing, etc.

When this has been completed it should be followed by a definition naming the class and grade required for every use to which structures are ordinarily put. This section should be

treated as a more detailed classification. It should contain all the requirements, specified as carefully as may be, as to manner of fireproofing, materials of construction, and general safeguards to be thrown around the occupants for their wellbeing and safety. This last should contain the requirements as to safety from fire, proper entrances, exits, etc., as well as the general sanitary regulations, specifying amount of space per person, ventilation, light, and proper placing of conveniences, and the numerous stipulations covering special hazards, as the storage of explosives, placing of automatic sprinklers, etc.

In this connection it will be found desirable to make special layouts for the treatment of such structures as tenements, apartments, workshops and factories, places of public assembly, theatres, garages, etc., which have a peculiar hazard. Everywhere it should be borne in mind that an architect, engineer, contractor or owner should be placed in possession of all necessary information to enable him to design and execute his work in conformity with the laws without any loss of time or fear of refusal of permit therefor. This requires that the laws give full and complete information all the way through, and that this will be found a distinct advantage, will hardly be denied.

But when all is said and done, the value of any law depends not so much upon what it contains as the ability, common sense and efficiency of those engaged in its administration and enforcement. It might be possible to write a theoretically perfect law and not find one piece of construction work correctly done under it. One of the prime requisites is the choosing of capable and broad-minded men to do this work, assisted by efficient, conscientious inspectors. Much can be done toward insuring a proper administration of the laws by so arranging the administrative portion that an intelligent man will catch hold of the right idea. Then conditions will be favorable for good building construction. On this account the administrative sections should receive very careful study.

SUGGESTIONS FOR A BUILDING LAW FOR THE CITY OF PITTSBURGH

ORGANIZATION AND ADMINISTRATION

The administrative portion should come first. It should establish the status of the Inspector and all the necessary assistants, name salaries that would attract the attention of good, industrious and capable men, and lay out the work to be done and the records to be kept sufficiently to give a capable man the right idea and have such flexibility that improvements in methods are not prevented but given every advantage.

A diagram, Fig. 1, is here given which appears to the writer to give a complete layout for the proper organization of a Bureau of Building Inspection for such a city as Pittsburgh. In explanation let it be said that under the present state laws, which are being revised, other bureaus have been established which would be brought into this suggested Bureau as divisions. The idea is simply to state what would make an efficient organization, to show how the work might be arranged to minimize the overlapping of the inspections, to save trouble and effort on the part of applicants for building permits who would no longer be required to take out a half dozen permits for as many different portions of a single operation and to so co-ordinate and arrange matters that all building inspection work, per se, would be under one organization. The advantages of so arranging this work, while easily perceived by those whose business it is to create efficient organizations, may be briefly included in the following statements. Those inspectors whose work is now quite similar in character would be placed in one class of work and those men would no longer follow each other over the same territory. Fewer men would be needed to accomplish the desired end. One head of each division remaining most of the time at the office could, by keeping an active system of reports, have control over his particular division and should be held responsible to the superintendent for the efficiency of his division. For each subdivision of the work, one of the inspectors should be regarded as "senior", his district being located downtown, and not so extended but that he would have time to confer at the general

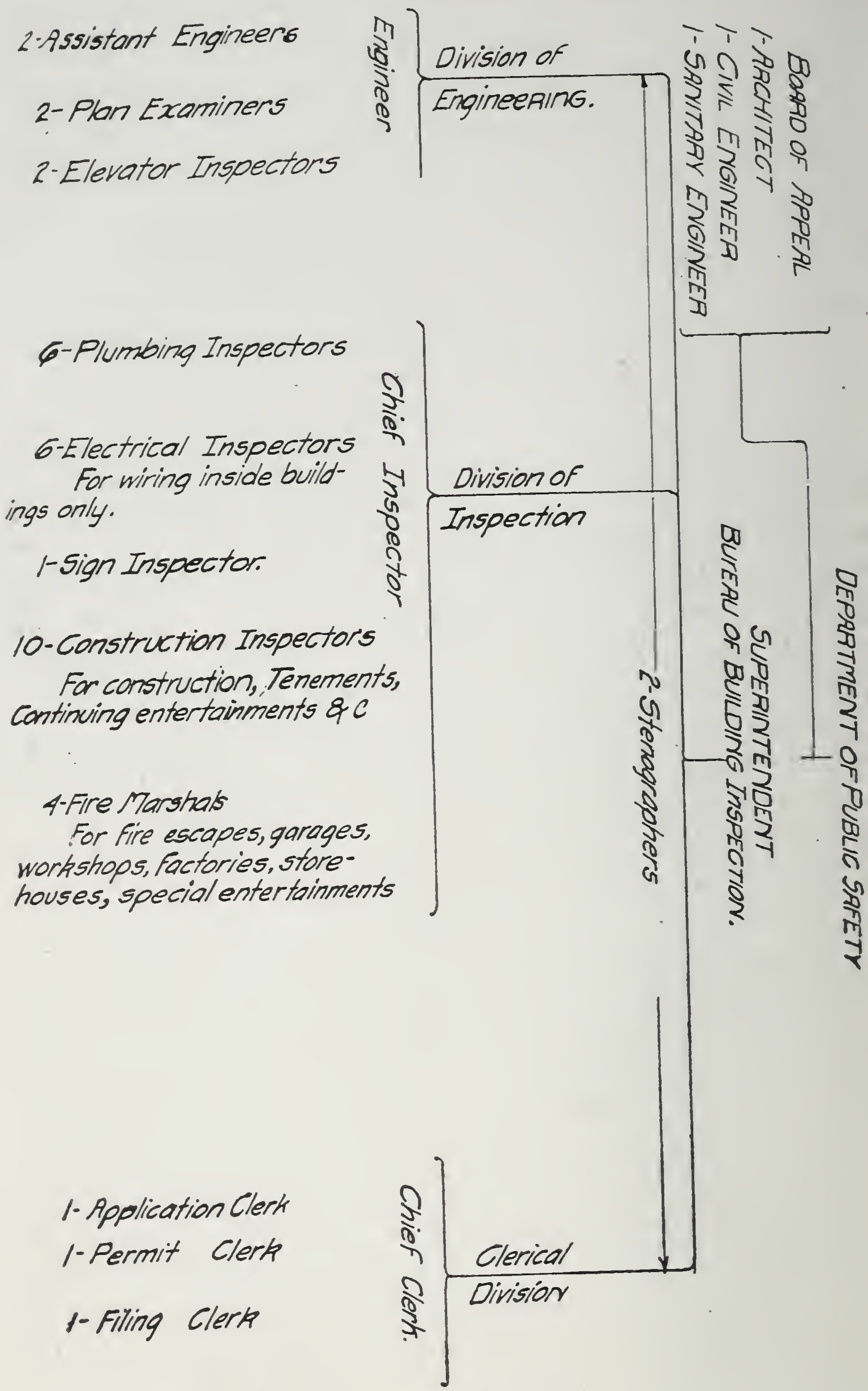
DIRECTOR
DEPARTMENT OF PUBLIC SAFETY
BOARD OF APPEAL
1-ARCHITECT
1-CIVIL ENGINEER
1-SANITARY ENGINEER
SUPERINTENDENT
BUREAU OF BUILDING INSPECTION.
2-Stenographers
Engineer
Division of
Engineering.
2-Assistant Engineers
2-Plan Examiners
2-Elevator Inspectors
Chief Inspector
Division of
Inspection
6-Plumbing Inspectors
6-Electrical Inspectors
For wiring inside buildings only.
1-Sign Inspector.
10-Construction Inspectors
For construction, Tenements, Continuing entertainments & C
4-Fire Marshals
For fire escapes, garages, workshops, factories, storehouses, special entertainments
Chief Clerk.
Clerical
Division
1-Application Clerk
1-Permit Clerk
1-Filing Clerk

Fig. 1.

office with the head of his division when needed. Division heads would be expected to confer and so arrange their work, under the general superintendent, that each item would be fully provided for.

A permanent Board of Appeal consisting of: One representative of each of the great divisions of the work to be covered should be provided for in order, as has been outlined previously, to decide appeals from the decisions of the building inspector, to pass upon rulings of the Bureau and to act as permanent commission for the advancement of the building laws.

In addition to the organization, the general manner of arranging the work should be laid down. The reports to be made to the City and to the State should be described so that an efficient head of the office would be able to catch the correct idea and do the work as desired. The general manner of procedure in taking out permits, in serving notice of violations of the laws, penalties for violating the laws, regulating permits required for change of occupancy and all such matters should have careful consideration.

It will be found to be of the greatest advantage to regulate the matter of building permits in general as follows: The permit given the contractor, engineer, or the architect should be for construction only. The application for permit should state in addition to other information, the intended use of the structure, leaving the classification of structure to the Building Inspector, under the law itself. Upon completion of the building operation, the owner should receive notice as to whether or not it is accepted by the Inspector and permit issued for a specified occupancy, if compliance with the laws has obtained. Successive permits should be required for each change in kind of occupancy. This would operate to prevent such a thing as a permit being taken out for a stable, building it of wood and then filling it full of automobiles, and trust to luck as to whether the law would hold them "if" they were found out. It would also give the Inspector a hold on the placing of an occupancy with a heavy hazard in an old building unfit to carry it. This control over occupancy would require very careful study, but could be worked out.

Another matter that is rarely found to be correctly handled in a "code" is the plans for a structure. In Cleveland duplicate sets must be given the inspector, both marked approved before permit for construction will be issued, one kept for the files of the inspector's office and the other returned to the contractor and kept by him for the inspector's use. One set of plans at the operation should be thus marked "Approved". Duplicates of those marked could be kept also, if desired. The inspector will thus be sure when he goes upon the job that the plans he looks over are the ones upon which permit has been issued.

This would add largely to the efficiency of the inspector's work. Two principal results would be noticed immediately. One of which is the Bureau's record in the files. Contractors and architects would have to file in the office of the inspector all plans covering changes in construction determined upon after such work had begun. This will make the file of plans in the inspector's office complete and correct. (Imagine going into the files to see if certain contemplated improvements or additions could be made with safety and finding that the plans kept there do not conform to the construction of a building.) The time wasted in getting correct data consumes the cost of making a correct record several times over as a rule. Then, an inspector, sure that the plans he is looking at are the approved ones, will take an added personal interest in checking over the construction by the plans. Result: Inspectors inspecting, and the feeling that they are working on a certainty causes them to take an added interest in their work. What man is there who, finding it does not make much difference whether he works or not, will not become disheartened thereby and lose efficiency, or else it completely wrecks his desire to be "on the job" when there is an air of uncertainty about things.

DEFINITIONS

This should be followed by a complete set of definitions, not an "attempt" but "definitions", of every name used. These should be *brief* but *accurate,* not containing specifications.

CLASSIFICATION OF STRUCTURES

This is one of the most important sections of the Building Law. There are many different opinions as to details. Suffice it to say that a perusal of the criticisms offered to the Pittsburgh Commission on the steel and concrete ordinances shows that not one offered thoughts on the general and broader aspects of the plan. Each individual correspondent read the ordinances, picked out a few details which he praised or criticised as his fancy dictated.

A carefully planned and well worked out building law will not, as some fear, supplant the work of the high class engineer, architect, or contractor; but on the contrary the general public will be led to appreciate the work that the really good professional men are doing, and this will lead to their sure employment, because the need for such experienced services will become apparent.

The following classification of structures was arrived at after considerable work on the inspection of buildings and a careful study of the laws of other cities, gleaning the best from each and writing it into this classification. Classification is made according to the requirements for resistance to fire hazard. Grade is given as definition of kind of occupancy.

CLASS I: Buildings in which all structural parts carrying loads or resisting strains are made of incombustible materials protected by fire resisting materials, and all walls, partitions, doors, trim and sash are made of fire-resisting materials all of which will fulfill the requirements given in the "Standard Table for Full protection", and all glass in windows, doors and transoms or skylights are made of wire glass. All openings through floors for fire-stairs must be made of fire-resisting enclosures, as given in sub-class *F, G* and *H* of Table No. 1. All floor openings other than fire stairs such as elevators, escalators and ordinary stairways must be completely surrounded with fire-resisting enclosures, as given in sub-class *H,* be provided with doors made of incombustible materials and wire glass, and have automatic fire doors for every opening. All partitions and enclosures to be otherwise as specified for occupancy. Occupancy

will then be defined, and the description of the requirements for each kind should be given under the heading: *Occupancy.*

CLASS II: Buildings in which all structural parts carrying loads or resisting strains are made of incombustible materials protected by fire-resisting materials and all walls and partitions are made of fire resisting materials which fulfill the requirements given in the "Standard Table for Full Protection". All doors, wall trim, window sash and floor finish may be made of combustible materials. All glass may be ordinary glass. All openings through floors for fire-stairs must be made of fire-resisting enclosures, as given in sub-class *N* of Table No. II. All floor openings other than fire stairs, such as elevators, escalators and ordinary stairways must be completely surrounded with fire resisting enclosures, given in sub-class *O* and *P*, and be provided with doors made of incombustible materials and wire glass or else have automatic fire doors for every opening. All partitions and enclosures otherwise to be as specified for *Occupancy.*

CLASS III: Buildings in which all structural parts carrying loads or resisting strains are made of incombustible materials protected by fire-resisting materials and all walls and partitions are made of fire-resisting materials which will fulfill the requirements given in the "Standard Table for Partial Protection". All other parts being the same as in buildings under Class II.

CLASS IV: Buildings in which all structural parts carrying loads or resisting strains are made of incombustible materials unprotected by fire-resisting materials. All walls and partitions being made of fire-resisting materials which will fulfill the requirements given in the "Standard Table for Partial Protection". All other parts being the same as in buildings under Class II.

CLASS V: Buildings in which all the structural frame, including walls, columns, beams and girders are made of incombustible materials unprotected by fire-resisting materials. All floors and partitions being made of fire-resisting materials which will fulfill the requirements given in the "Standard Table for Temporary Protection". All doors, finish, trim, window frames and glass being constructed of combustible ma-

terials and ordinary glass. All openings through floors for fire-stairs to be fire-resisting enclosures, as given in sub-class *W, X* and *Y* as specified for *Occupancy,* and must be provided with automatic firedoors of the same fire resisting quality as the enclosures or else doors made of incombustible materials. All partitions and enclosures otherwise to be constructed as specified for *Occupancy.*

CLASS VI: Buildings in which all structural parts carrying loads or resisting strains are made of combustible materials but which fulfill the requirements given and specified for slow combustible construction. All outside walls being made of fire resisting materials which will fulfill the requirements given in the "Standard Table for Full Protection". All fire enclosures and partitions to be the same as in buildings under Class II.

CLASS VII: Buildings in which all structural and other parts are made of combustible materials.

FIRST GRADE: All buildings devoted to the use of the general public for purposes of state or of public assemblage.

Division "A": PUBLIC BUILDINGS PROPER. Buildings designed to be occupied by state, county or city administration offices, court rooms, libraries, museums, art galleries or council chambers.

Division "B": SCHOOL BUILDINGS. Includes all school, college or other buildings, containing class, drawing or lecture rooms or rooms for the purpose of education or instruction. If any such building has an assembly room of greater seating capacity than four class rooms such assembly room will be considered as an Assembly Hall and subject to the requirements therefor.

Division "C": ASSEMBLY HALLS. Includes all churches, convention halls, auditoriums, exposition buildings, music halls, railroad departments, or any part of a building containing an assembly room holding more than 100 people.

Division "D": THEATRES. Includes all theatres, opera houses, play houses, pavilions, or any assembly hall designed or used for the entertainment of spectators having a permanent stage upon which stage scenery and theatrical apparatus is employed.

Division "E": DETENTION BUILDINGS. Includes all public or private hospitals, reformatories, prisons and police stations.

Division "F": PUBLIC UTILITY BUILDINGS. Includes all other buildings owned or used by the general public but not classified in the foregoing divisions.

SECOND GRADE: QUASI-PUBLIC BUILDINGS. Includes all buildings used for the public shelter either for purposes of business, or for temporary abode or habitation.

Division "A": HOTELS. Includes all hotels, public inns, or any building or part thereof designed to be used for supplying food or shelter to residents or guests and having a public dining room, cafe or office or either. A public lodging house or a building used only for the shelter of residents or guests will be classified as a hotel.

Division "B": OFFICE BUILDINGS. Includes any building designed or used for office purposes in the conduct of general business, but may have a store or sales rooms on the ground floor. No part of such a building shall be used for residence except by the janitor and his family.

Division "C": STORE BUILDINGS. Any building designed or used for the sale of merchandise or objects of utility or general supplies.

THIRD GRADE: INDUSTRIAL BUILDINGS. Includes all buildings designed or used for the manufacture or storage of merchandise.

Division "A": FACTORY BUILDINGS. Includes all buildings designed or used for the manufacture of merchandise by machinery. All printing establishments will be classified as factory buildings.

Division "B": WORK SHOPS. Includes all buildings designed or used for the manufacture of merchandise by hand.

Division "C": MILL BUILDINGS. Includes all buildings designed or used for the manufacture and storage of heavy machinery, structural steel shapes or bars, or castings, and machine shops.

Division "D": WAREHOUSES. Includes all buildings designed or used for the storage of general merchandise or food or other supplies.

Division "E": GARAGES. Includes all buildings designed or used for automobile livery or storage, where five or more automobiles, carrying tanks containing fuel, any volatile or inflammable material, are kept.

Division "F": SLAUGHTER HOUSES. Includes all buildings designed or used for the slaughter of animals, the curing, drying or preparation of meat or the by-products thereof, or the rendering of fat or manufacture of soap. bonedust, fertilizer or other animal product.

FOURTH GRADE: TENEMENTS. Includes all buildings containing suites or apartments used for the permanent habitation by more than two families living independently of each other.

Division "A": APARTMENT HOUSES. Any building or any portion thereof designed or used as a residence for more than two families living independently of each other, and in which every family or household shall have provided for it a kitchen, set bath tub and water closet separate and apart from any others. A store on the ground floor will be classed as an apartment for one family.

Division "B": CLUB HOUSES. Includes all buildings used or intended for use by an organization or society for mutual entertainment or recreation having a common kitchen, dining room and other rooms of utility and recreation and containing lodging apartments for the use of the members of the organization only.

Division "C": TENEMENT HOUSES. Includes all houses, buildings or portion thereof which is designed to be used or occupied as a home or residence of more than two families living independently of each other and doing their cooking upon the premises or by more than two upon any floor so living and cooking but having a common right in the halls, stairways, yards, or water closet. A store on the first or ground floor will be considered the same as a home for a family.

FIFTH GRADE: DWELLINGS. Includes all buildings which are designed or used as the home or residence of not more than two separate families in which not more than ten rooms shall

be used for the accommodation of boarders, no part of which is used as a store or for any business purpose.

Two or more such dwellings may be connected on each story when used for boarding purposes provided the halls and stairs of each house shall be left unaltered.

Dwellings built in terraces more than three stories high having two distinct families living independently, or a family on upper floors with a store below will be classed as a tenement house.

SIXTH GRADE: Includes all buildings used for the shelter of animals or vehicles.

Division "A": STABLES. Includes all buildings designed or used for horse livery, boarding or private stables or barns, carriage houses, sheds, pens, coops, stockyards with attendant slaughter pens or any building for the feeding or sheltering of animals or fowle.

Division "B": GARAGES. Includes all garages designed or used for the shelter or storage of automobiles for private use only where not more than five automobiles are kept.

SEVENTH GRADE: TOWERS. Includes all structures designed or used for water storage, for sprinkler systems or other purposes. A water tank for any purpose, placed in or near a building whether supported by separate tower or not will be classed under this grade.

EIGHTH GRADE: Includes all buildings or structures not classed in grades one to seven. For the purpose of this law, fences, bill and sign boards and all signs shall be classed as structures of this grade.

OCCUPANCY: Following this, the name and definition of every kind of use or occupancy should be given, naming the class and grade under which they must be constructed and specifying all the additional requirements necessary in order to provide for the hazards occurring in each. This will cover such uses as Tenement Houses, Theatres, Nickelodeons, Assembly Halls, Office Buildings, Factories, Warehouses, etc., etc. These additional requirements will cover electric wiring, plumbing, etc., as well as general sanitary conditions and many others. This is the longest, most wordy and tedious of the various por-

tions of a building law and must be passed over very briefly in such a discussion as this. Mention, however, must be made that all the requirements for each kind of occupancy should be exhausted under its heading, even if there might be some duplication of requirements for other occupancies. This is advocated simply as a method to help to make the laws clear and easy for reference for the convenience of those who must use the code daily. It will be found that such an arrangement renders it less easy to make mistakes in planning a structure, or in enforcing the laws.

CLASSIFICATION OF MATERIALS AND METHODS OF CONSTRUCTION

Following the classification of structures should come a careful description and specification for the materials of construction. This should be accomplished in a great measure by classifying special requirements such as: "*A*", Fire Resisting Properties; "*B*", Resistance to Strains; "*C*", Permanency of Construction; "*D*", Maintenance and Preservation; "*E*", Sanitary Condition, etc. All classifications should be worked out properly to suit the risks involved. Requirements more severe than necessary to bring about proper application of construction to evenly balance the hazard should not be advocated. Short descriptions should be interwoven with the technical specification in order to popularly summarise the reasons for their use to correspond with the hazard. This last will do much toward removing popular prejudice against the requirements and to prove that the specifications are not more severe than necessary. All classifications should be worked out with the end in view of placing the use of all materials and methods of construction on a basis of merit alone. It should specify results only, since the result desired is the end in view. It should not contain an endless amount of aglomerated details setting forth how the result must be obtained, but it should leave all this to the inventive genius of engineers and the story told by the testing apparatus. Physical tests will do more to remove the doubt as to safety or danger of construction and to prove how Nature, the great solver of all problems, will solve those which come under observation in building operations. Requirements

placed against the physical testing apparatus should never be any more severe than obtain under the actual conditions of service. Observation should be carefully made under these conditions. Now this means just exactly what it says. It means that the day of the careless engineer in these matters is ending. A new era is coming. Methods of construction will be improved, the quality more certain and conditions of occupancy, after the construction, more closely supervised. When this has been accomplished, factors of safety can be kept the same and cost of construction lowered. It will then be seen that the present extravagance, called a factor of safety, will be much reduced.

Classification of materials covering fire resisting qualities is now receiving careful consideration by the National Fire Protection Association, and the U. S. Bureau of Standards at the Butler Street Laboratory in this city. It received its impetus at the International Fire Prevention Congress held in London in 1903 by the British Fire Prevention Committee, and the National Fire Prevention Convention held in Philadelphia, Oct. 13-18, 1913.

The tables here given are built up around the information gained from study of the requirements laid down by the foregoing organizations* and differ from them only in two or three cases where experience has suggested that a sub-class might be added to provide for conditions which are less severe than those called for by the requirements. In addition to this, the information given under the column, "Remarks" and at the bottom of the Table as "Notes" has suggested itself to the writer as a brief way to tell the story of how the different parts of a structure may be construed to suit the requirements.

Classification of materials from other standpoints has been given careful study by the writer. However, this is a difficult matter to cover completely in a short time and the work is not in shape to present at the present time. Nothing has been done as yet in this direction, so far as can be learned. The progress

*The compilation was made by a committee appointed by the Gypsum Industries Association, of which Virgil G. Marani, Cons. Engr., Cleveland, Ohio, was Chairman.

TABLE NO. 1.

Standard Table for Full Protection

Type of Construction	Sub Class	Duration of Test Min.	Aver'g Temp. Deg. F.	Thickness Material Inches	Area of Test Panel Feet	Water Test: Time Min.	Water Test: Nozzle Diam. In.	Water Test: Pressure Lb. per Sq. In.	Water Test: Flooding	Remarks
Protection of Structural Frame		240	1700	2 or more		10	$1\frac{1}{8}$	60		Metal fully protected from corrosion by coating
Fire Resisting Floors		240	1700		100 sq. ft.	10	$1\frac{1}{8}$	60	Flooding optional.	See notes * & †
Fire Resisting Roofs		180	1700	3 or more		5	$1\frac{1}{8}$	30	Flooding optional.	
Partitions, Fire Division		180	1700	5 or more	$9\frac{1}{2} \times 14\frac{1}{2}$	5	$1\frac{1}{8}$	50		For dividing stores & important Floor areas
Partitions,—Important **	A*	120	1700	5 or more	$7\frac{1}{4} \times 9\frac{1}{2}$	5	$\frac{7}{8}$	50		For office buildings & Storage Warehouses
	B†	120	1700	4 or more	$9\frac{1}{2} \times 14\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{8}$	30		To separate office from operating room—Factories
Partitions,—Minor **	C	90	1700	4 or more	$9\frac{1}{2} \times 14\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{8}$	30		Non bearing,—length = 3 × height
	D	60	1500	4 or more	$9\frac{1}{2} \times 14\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{8}$	30		Non-bearing, length = $2\frac{1}{2}$ × height
	E	45	1500	4 or more	$9\frac{1}{2} \times 14\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{8}$	30		Non-bearing, length = 2 × height
Fire Resisting Enclosures	F	240	2000	6 or more	$9\frac{1}{2} \times 14\frac{1}{2}$	5	$1\frac{1}{8}$	50		To separate Fire exit from main Floor in workshops
	G	120	1700	5 or more	$9\frac{1}{2} \times 14\frac{1}{2}$	5	$\frac{7}{8}$	50		To separate Fire exit from main Floor in stores
	H	90	1500	4 or more	$7\frac{1}{4} \times 9\frac{1}{2}$	$2\frac{1}{2}$	$\frac{7}{8}$	50		To separate Fire exit from main hall in tenements

*Standard Specifications of National Board of Fire Underwriters.
†Standard Specifications of American Society for Testing Materials.
Note that floors and roofs to be designed for loadings to suit use of building.

**Note that all partitions to be constructed entirely of materials that will not support combustion, and to be securely keyed to floor slabs, attachment to withstand test.

TABLE NO. 2.

Standard Table for Partial Protection.

Type of Construction	Sub Class	Duration of Test Min.	Aver'g Temp. Deg. F.	Thickness Material Inches	Area of Test Panel Feet	Water Test: Time Min.	Water Test: Nozzle Diam. In.	Water Test: Pressure Lb. per sq. in.	Water Test: Flooding	Remarks
Protection of Structural Frame		180	1700	1½ or more		5	1⅛	60		Metal fully protected from corrosion by coating
Fire Resisting Floors		180	1700		100 sq. ft.	5	1⅛	60	Flooding optional.	
Fire Resisting Roofs		180	1700	3 or more	100 sq. ft.	5	1⅛	30	Flooding optional.	
Partitions, Fire Division		180	1700	5 or more	9½×14½	5	1⅛	50		For dividing important fire areas
Partitions,—Important	I	90	1700	5 or more	9½×14½	1½	1⅛	30		Bearing = length = 3 × height
	J	60	1700	4 or more	7¼× 9½	1½	1⅛	30		Bearing length = 2½ × height
Partitions,—Minor	K	90	1700	4 or more	9½×14½	1½	1⅛	30		Nonbearing length = 3 × height
	L	60	1500	4 or more	9½×14½	1½	1⅛	30		Nonbearing length = 2½ × height
	M	45	1500	4 or more	9½×14½	1½	1⅛	30		Nonbearing length = 2 × height
Fire Resisting Enclosures	N	180	1700	6 or more	9½×14½	2½	1⅛	50		To separate fire exit from main floor in schools
	O	90	1500	5 or more	9½×14½	2½	⅞	50		To separate fire exit from main floor in theaters
	P	60	1500	4 or more	7¼× 9½	1½	⅞	30		To separate fire exit from hall in office buildings

Note: That all partitions are to be constructed entirely of materials that will not support combustion, attachment to be secure and withstand test. That floors are to be designed to suit use of building: That elevator enclosures, and doors are to withstand same test as fire division partitions.

TABLE NO. 3.

STANDARD TABLE FOR TEMPORARY PROTECTION

Type of Construction	Sub Class	Duration of Test Min.	Aver'g Temp. Deg. F.	Thickness Material Inches	Area of Test Panel Feet	Water Test				Remarks
						Time Min.	Nozzle Diam. In.	Pressure Lb. per sq. in.	Flooding	
Protection of Structural Frame		90	1700	1 or more		2½	1⅛	30		Metal fully protected from corrosion by coating
Fire Resisting Floors		90	1700		100 sq. ft.	2½	1⅛	30	Flooding optional	
		60	1700		100 sq. ft.	1½	1⅛	30	Flooding optional	
Fire Resisting Roofs		90	1700	3 or more	100 sq. ft.	2½	1⅛	30	Flooding optional	
Partitions, Fire Division		90	1700	4 or more	9½×14½	2½	1⅛	30		For division walls between suites in tenements
Partitions,—Important		60	1500	4 or more	9½×14½	1½	1⅛	30		Bearing-in
		45	1200	3 or more	7¼× 9½	1½	⅞	30		Non bearing, in residences
Partitions,—Minor		45	1500	3 or more	7¼× 9½	1½	⅞	30		Non-bearing,—Length = 2½ × height
		30	1200	3 or more	7¼× 9½	1½	⅞	30		Non-bearing,—Length = 2 × height
Fire Resisting Enclosures		90	1700	5 or more	9½×14½	2½	1⅛	30		To separate fire exit from main floor in nickelodeon
		60	1500	4 or more	7¼× 9½	1½	1⅛	30		To separate fire exit from main floor—assembly hall
		45	1500	3 or more	7¼× 9½	1½	1⅛	30		To separate fire exit from main floor—hotel or lodging

NOTE: That all partitions except "minor" are to be constructed entirely of materials that will not support combustion, attachment to be secure and to withstand same test: That elevator enclosures and doors to withstand same test as fire division partitions: That all floors are to be designed for loadings to suit use of building.

achieved so far by the writer in his work has come from requiring those interested in various building materials to conduct physical tests as fast as possible, and submit reports of all tests, giving information relative to its use, and to place in writing specifications for their use and methods of conducting calculations for suitability in its proposed installations. This has been made to cover several materials for non-bearing partitions, several "systems" of reinforced concrete construction and waterproofing compounds for concrete. The matter of preservative coatings for steel has been brought to the writer's attention quite recently. When the information is at hand, those points now covered by law are separated from those that are not, and decision is made as to the manner in which the Inspector will check the work in order to make the construction proposed as safe as other types covered by law and ordinance. The principles of good engineering are strictly adhered to. When a decision has been reached and agreed to by those proposing to use a method of construction, or building material, a specification covering its use is written and sent to the interested party. All information, tests, reports and correspondence is then filed together with the specification covering its use for future reference. The advantage in this procedure being that, after all this has been done, users of a given material will know exactly what will be passed by the Bureau and can go ahead with perfect confidence, knowing that the material may be used. Also this method of procedure insures uniformity in decisions by the Bureau, avoiding the oft-repeated claim that one man is given advantages which are refused another. It also aids in correctness of decisions. When decisions are made, they have been thoroughly discussed beforehand and the decisions are much more apt to be correct.

In the tests made for various methods of applying steel reinforcement to concrete, strain gauge test readings are required on steel and concrete, taken at the same time the applied load, which equals the live load for which the structure is designed, is so placed within the structure as to produce the heaviest strains likely to occur in its practical use. However, such conditions are never required to be any more severe than

this. When this information has been correctly obtained, then assumptions and theory must be worked out to a sufficient state of completeness to insure that an estimate of the strength may be made with sufficient accuracy to come within the limits of uniformity of construction and behavior of materials.

METHODS OF CALCULATION

The discussion immediately preceding has quite an important bearing upon the general method to be followed in making design calculations. Everywhere in nature the keen student observes a uniformity of procedure. The same causes produce the same results under the same conditions everywhere. This shows that all problems will be solved in nature, in a certain way, under certain conditions. The solution will be worked out by Nature in her own way regardless of the hopes, desires, or assumptions of man. Man has created a science called Engineering.

An important work which should be done by engineers is the observance of the behavior of structures after completion in order to arrive at a basis for comparison of other structures under similar conditions, or for predicting the probable behavior of a similar structure under samewhat different conditions. It is the province then of the scientist to formulate theories and methods of calculation which, worked out for the conditions in hand, will result in a correct estimate as to what will be the result of doing certain predetermined things.

Engineers frequently lose sight of this reasoning. At times they fall into the habit of analyzing mere definitions and postulates, assuming that the results correspond exactly with the physical conditions in the materials doing the actual work. Avoiding any metaphysical discussion of nominalism and realism, it is not hard to see that no set of symbols can fully represent physical conditions. Adding to this the uncertainty arising from lack of ability to see into the future far enough to foresee how much abuse a structure may receive, the necessity of factors of safety sufficient to cover such liabilities and hazards is apparent. It is important to check the assumptions and theories by actual experiments and physical measurements of materials, noting their quality and behavior in the structure

after it has been assembled. The condition which all are trying to foresee is just this and nothing more. It is the wise man who goes directly to the source for all information needed in the conduct of his business. Wisdom and judgment are needed, common sense must be applied to these matters. Experiences the writer has encountered, have led him to think with the editor of "Engineering" (London): "Common-sense without mathematics will do a great deal, common-sense with mathematics will usually do more; but mathematics without common-sense, what need be said."

Whenever a natural process is to be represented by a set of mathematical or other symbols, it is well to remember that the artificial statement often expresses more than actually obtains in nature, because in the physical world only changes of certain kinds occur. It is well than to limit the generality of mathematical expression and to come to a realization that a test on actual structures under service conditions, while it may not offer a more precise verification of classical mechanics, does lead rather to correction of principles considered *a priori* as rigorous.

Now what has all this to do with the matter of building laws, particularly methods of calculation? Simply this: It is to point out forcibly, in laying down mathematical assumptions to be followed, or the mathematical processes which it is intended shall be used in making calculations for strength of a structure, that they are simply the fine tools of a very skilled workman, and must be used as such. Just as a good carpenter never would try to make a square hole with a gouge, so is it necessary for methods of calculation, laid down as sacred and not to be violated in a building law, to fit the use for which they are intended in the best manner known to man.

Thus, while a building law need not attempt to assume the proportions of a text book on the subject, or any phase of it, yet sufficient information as is sure to be needed by a designer to give him opportunity to do his work under the law correctly and have it pass the requirements without annoyance or delay, is necessary. This will have been accomplished when all requirements for safety have been clearly stated.

It is inexpedient to try to place full details in this paper, hence it is sufficient to state that strict adherence to these principles will, in the experience of the writer, produce the desired result if it is remembered always that it is a building law that is being prepared and not a specification.

In view of the fact that it is manifestly inexpedient to attempt to include a whole sample building law in a discussion of this character, the author desires to have the following conclusions strongly emphasized:

First: That building laws are a necessity of modern living conditions and it is the function of government to look out for the people's good in all things.

Second: That building laws are legal, and are based on the right of the people to lay down and enforce the principles under which they will live.

Third: That they ought to be made to suit living conditions and not to serve special interests, political, financial or otherwise.

Fourth: That they are not a simple thing to make; that their preparation should be placed in the hands of those who have prepared themselves in the various phases of the safe construction and use of structures; that only those who are the broadest minded, best prepared and most vigorous in the community should be entrusted with their preparation, and that they should be paid properly for their work.

Fifth: That the laws when prepared should bear the attitude of guiding the prospective builder in the direction of safe construction rather than of preventing the recurrence of a hetereogeneous lot of unsafe or undesirable conditions.

Sixth: That the laws should be carefully arranged in proper order, such order being about that followed in planning a structure, and the information should be carefully edited, *properly indexed for ready reference,* and each division be completely treated before attempting to display the next in order, thus avoiding the annoyance of vagueness. That they contain wise provisions in all their portions. That uniformity of result be the continual object thereof and equity between all interested parties be preserved as a fundamental principle, that the gov-

ernment provide a fair deal for all, and last that they provide for the constantly progressing state of the science of engineering and art of construction.

DISCUSSION

Mr. Richard Hirsch:* Have these Commissions done anything other than to look to the constructive safety and fire protection of buildings? Have they looked to the class of buildings which may be permitted in certain districts? For instance, a church organization might have a very valuable property, with no guaranty that there will not be a car barn put up next door. Or there may be a vacant lot across the street from one's home, and the owner have no guaranty that there will not be a blacksmith shop put there. It seems to me that regulations of that sort should be effected by ordinance just as much as the width or grade of streets. I believe elsewhere, abroad particularly, they go into those things. I would like to know to what extent they have done so in this country.

The Author: I do not believe that this matter can be found in a building law in this country. Examination of many proposed building laws shows the matter has not yet reached this stage. Abroad, especially in Germany where the paternal attitude of the government is much more apparent, these things are carefully considered and, judging from present agitation I think it will not be long until the governments, acting for the welfare of the people will study carefully the matter of districting cities; that is, keeping factories in a certain neighborhood, most suited to their work, placing the workman's home close enough for convenience but far enough away for other considerations and making districts for the various kinds of houses. This is another broad phase of the subject. It is one that will soon be studied. It would tend to mitigate the evils spoken of.

Replying directly, the loss to an owner of property value due to the obnoxious use to which an adjoining property may be put can be considered to come under the general principle

*Mechanical Engineer, H. K. Porter Company, Pittsburgh.

that an owner may use his property as he sees fit as long as he does not thereby injure his neighbors' property.

MR. EDWARD GODFREY: I would like to ask Mr. Ferguson as to his interpretation of the Pittsburgh Building Code regarding girders. The code says that girders shall be designed for their moments of inertia. Does that mean gross section or the net section of the parts? If we take the gross section of the girder including bottom flanges and all wouldn't that come under tension members which must be designed by their net section?

THE AUTHOR: It would take a very long time to answer this question. If the questioner will come to my office, I will explain this question in detail.

MR. VIRGIL D. ALLEN:* Your speaker has well said that the question of code writing is a very important one. I do not believe there is any problem before the city governments now that is more important unless it is the question of finance. The code is really a four part law. The first part usually is the consideration of strength, i. e. safety from the view point of structural provisions. Second is the fire hazard. Third is the proposition of housing. And there is another value to the code which is not contemplated in the police power at all, under which codes are written, yet it is a very real value, and one which I think code students are beginning to appreciate, and that is of setting a standard of excellency in the code for every city.

In regard to the writing of the various branches of the code, there is no difficulty at all in writing the engineering section if one can keep the commercial interests away while doing it. It is all founded on a fairly exact science at the present time. We know what steel, stone and concrete are good for, and if we give ourselves a fair working factor of three or four there is no danger of a structure failing on account of bad engineering unless some one wilfully puts up something different from what they started to do, or overloads the structure afterwards.

When we get into the subject of fire hazard we get onto more difficult ground right away. This is based on a matter

*Building Inspector, Cleveland, Ohio.

of judgment and personal experience largely and we get opinions varying 100 or 200 percent.

When we get into the subject of housing we are even further away from exact science. One man may want the sun shining in his room all the year round and another does not want it to shine in his window at all.

This matter of State Code writing is something my face is turned squarely against. The moment a State Code is written we have got to do what the speaker of the evening said, make it so it will bear uniformly throughout the entire state. In Ohio we have Cleveland on the shore of the lake, laid out on perfectly level ground, sandy soil, and with a certain population. Columbus is in an entirely different situation and Cincinnati is still different. Every city has its varying conditions, topography, climate, population, habits, arrangement of streets, etc. In Columbus the lots were originally laid out 62½ ft. wide and 187½ ft. deep. After while they split them up into 31¼ ft. and then into 16⅛ ft. lots. Regulations that would work on a 40 ft. lot in Cleveland would be difficult to apply in Columbus.

A State Code which must apply to all the cities of the state is in the first place very difficult to write. It is about all I can do to write a code for one city. I do not know how I would start to write a code for the entire state. A State Code immediately calls for an organization, and then you will have an organization at Harrisburg, that will finally spread itself out to control local conditions. That is a political machine in the last analysis. Some of us may like that and some may not. I am against it.

Then how about passing on plans under a State Code? Are we to be compelled to spend money to go to the Capitol every time an argument is raised? That would be rather expensive and it would require a large organization to handle the work. I think it kills the local initiative of cites to have a State Code. They begin to regulate the district in different sections, the residential district, the factory district, etc. You can not do that by a State Code in all the cities of the state. It would be a physical impossibility. The worst about that is

the difficulty of changing. Cleveland would be absolutely helpless if we had to go to the legislature to have our code changed. We have had a State Code foisted on us which is a nuisance and will be more of a nuisance as time goes on. The legislature meets once in two years, and all know what a scene of log rolling the legislature is. If a Building Commissioner went to the Legislature to get a change made, he would have little chance unless he had some powerful interest log rolling with him, which of course would not be the case if he were trying to get something through for the general good.

And last but not least it is absolutely undemocratic. I believe in home rule and I do not believe in any foreign potentate ruling. Neither do I believe in any State Commission ruling any city in regard to its building regulations. Building regulations, as has been said, are part of the police power. Why not have the Adjutant General of the state run the police force? There is just as much reason for that as to run the building department. If you think there is no danger of the state injecting itself into building operations I will point you to an example. The State Code of Ohio says in the first section that it shall be the duty of the state inspector of work shops and factories, or of the state board of health, or building commissions, or building inspectors, where they have a building department, to enforce the provisions of this act. In another section it says that where another device or construction is proposed it shall be submitted to the proper state and municipal authorities which shall pass upon it. Now the first section says the commissioners, state inspector of work shops, or bureau of health, or building inspector, whoever may be the one. The state inspector of one department has written into that department of our code a provision that a certain part of a building construction must be made of a certain type and form of material. I wish to avoid mentioning names. I do not know what he is going to do next. He is bound to read into that second section that the state *and* local authorities must pass on this question, because he knows that I am not going to enforce that provision which he has read into the act. That is what you will be up against if you have a State Code.

I understand from your speaker that you have already been delayed in some way in the work of writing your own code by virtue of some interference with the state code. I believe it is possible to have some things in a state code, perhaps in the form of a general standardization of definitions, the meaning of terms, etc., perhaps you might establish some minimum requirements, the very least that any village or community ought to have, a minimum requirement for safety, a minimum width of streets or something of that sort. I am not certain how far it should go, but not very far. The argument over in Ohio is that all the people in the country need protection. They tell us how many million people in Ohio need protection. The fact is nobody needs any particular protection under the police power in the form of a building code except people in large cities. They are not sincere in Columbus when they tell me that.

Mr. Elliott told the speaker about the earnest cooperation of the commission with the Code Commission in Ohio. Well a committee of seven made some objection because the state commission was going to push a code right through the legislature and not let anybody know anything about it. They sent out a notice just a few days beforehand, not nearly long enough to give the matter any consideration at all. We went down to Columbus and it did not go through and it has not gone through yet.

I am not at all familiar with your code in Pittsburgh and so will not attempt to discuss it. I judge your building department is no larger that it ought to be. I know that is true of our city. We can not possibly cover the ground. In regard to writing the code I really think, and this is based upon our experience up there, that the building department should do most of the code writing, because you have presented to your building department every possible form of objection that can be thought of in regard to the code and therefore that department is familiar with every point of friction.

Something was said about the difficulty of a layman committee working on this subject, like a code committee of the council. They are absolutely incompetent to deal with this code question. As an illustration in point, we have a tenement

house code which was worked out in two or three years by a committee of the Chamber of Commerce with which I cooperated. It was finally introduced in council and the objections began to come in as soon as it was published, and there were some features radical enough to excite considerable antagonism. The committee of council spent a great deal of time on the matter and did the very best such men could possibly do. I do not think any five men could have done better with their skill and training along this subject. But after they listened to all of it and sat down and heard it all over in an executive session, they turned it over to me and said "straighten it all out and turn it back to us". The thing is on my desk now for final solution, if I can work out a final solution.

I started in about two years ago to rewrite the building code of Cleveland. We have written about 41 percent, I have 5 percent more ready to submit to council, and we have preliminary studies on what would amount to 10 or 15 percent more. This has been done almost entirely by the speaker and his assistants. We have had to do it nights and Sundays and at odd times we could get from the pressure of work. It has taxed our energy right up to the limit. I got a sub-committee of the Building Code Committee of the Engineering Society, the Chapter of Architects and the Builders Exchange to act as a joint committee. They sat every Friday from 1:00 to 3:00 o'clock to get the matter in the best form for presentation. There were anywhere from 3 to 10 present and we have had some night meetings. Some sections of that code have been submitted to the committee nine or ten times. After we have finished a section and put it in logical order it is sent to council for final action. That committee has had a great many meetings. The work has been done gratuitously. The members have worked very faithfully and intelligently and I for one value very highly the advice and help I have received from these gentlemen, and it has been given in the most courteous and kindly spirit. They submerged, as nearly as a group of men could, their own individual and personal interests and oftentimes stood for things they knew might in some ways hurt their personal interests, because they could see the value of it.

I just want to say one thing in relation to this, that there is no better way of making a law than to have the people make the law themselves. I believe in direct legislation. When a man is making his own law he is thinking about it, and if he makes it he is more likely to live under it and be satisfied with it than if he has a better law handed to him by an external power of which he knows nothing. And I want to say that I have had scarcely a complaint upon any section that we have written in the manner I have described.

Mr. J. J. Shuman:* I have little to say except to express my gratification at what I have heard here tonight. I am with one of the large steel companies, my work being largely in the study of specifications, and recently have had to look over quite a number of specifications in state and city codes. The steel companies are viewing with some little concern the spread of this code idea, not because a code is not a good thing, but because the writing of codes has apparently been influenced in some cases by agencies over which those nearest in interest have had no control.

The feature of state codes, and in less degree of city laws, which gives manufacturers some concern, is the difficulty in obtaining revisions when undesirable clauses are discovered. Once made into law such specifications are almost unchangeable.

The thought I wish to express particularly is that if any of you gentlemen are entering on the writing of codes do make them as general and as simple as you possibly can. Do not run in a lot of details that would look, even if it is not actually so, as if they were put in in the interest of some patented or proprietary article.

If you look at this whole thing more broadly you will see just what this idea of state codes means. This country is undergoing at the present time an activity that seems to point towards the centralization of government, and we are not going to end with state supervision of details that should be taken care of locally, but gradually if the present trend persists we shall have every activity centered at Washington, the very worst thing that could happen to us. I am certainly with our friend

*Inspection Engineer, Jones & Laughlin Steel Co., Pittsburgh.

from Cleveland who speaks for self-government. We don't need this state interference, we don't need this national interference; we are capable in each of our great centers of taking care of our own details and we want to be permitted to do it.

MR. C. G. DUNNELS: In reading over this very opportune paper, I was impressed by the vast difference between the condition of affairs as they now exist in the city of Pittsburgh and the ideal conditions as suggested by the writer. With the exception of the ordinances prepared by the recent Building Commission, the building laws of this city are about as intelligible as if written in the hieroglyphics of Egypt. It is almost impossible to find out what is permitted and what is prohibited without making a personal visit to the Superintendent of the Bureau of Building Inspection, for, practically, the Building Law of this city is a summary of decisions made by the Superintendent.

It certainly would do away with considerable adverse criticism if the building laws were put into such shape that there could be no unintentional or intentional misunderstanding of the provisions of the law. It has seemed amazing that a so-called "business administration" could be so short-sighted as to fail to see the value of the work done by the recent Building Commission.

I know that the Bureau of Building Inspection would welcome ordinances so worded that their meaning would be plain, thus relieving the Bureau of the responsibility of constantly making decisions which may seem fair or otherwise.

The suggestion of a permanant Board of Appeals is a very good one and one which should be adopted by this city whether or not our building laws are ever made modern. This Board could act as a Commission to which could be presented suggestions for revisions that might arise from time to time.

Slowly we are coming to realize that the German idea that the rights of the community are more important than the rights of any individual, that liberty does not mean license. The question of building laws affects every inhabitant of our city, for we must all have our homes in buildings and the majority of us work in buildings. We must protect ourselves and fami-

lies from the fool or knave who erects a fire trap or an unsafe structure. Strange as it may seem a great number of our poorly constructed buildings are owned by wealthy estates and individuals. When they build, their constant instructions to their architects are to plan the construction so that it will just come within the law.

It is sincerely to be hoped that at no distant time a new commission will be created which will finish the work so well begun by the Building Commission, which lately went out of existence.

Mr. Edward Godfrey:* The prime object of a building code is to insure the building of safe structures to the end that life and property be conserved. The idea in writing a building code frequently seems to be that of letting in the particular system of design controlled by one interest, and keeping the other fellows out. In New York, for example, they tried to eliminate reinforced concrete by the foolish requirement that slabs be ¾ in. deep for every foot of span. Imagine an office building with 12 ft. spans 9 in. deep. Such absurd requirements have no place in a building code. They do not make for safety nor economy. They have absolutely no purpose but to give a monopoly to some other kind of construction than reinforced concrete.

When the Pittsburgh Building Code was being prepared a great hue and cry went up from the cement interests because of the wording of the definition of Portland cement. And now the definition reads "and to which no addition greater than 3 percent has been made subsequent to calcination". If it should develop that a material superior to Portland cement, as defined by this code, can be produced by adding sand or other inert substance and re-grinding, an owner is estopped from using this superior material by this definition.

Sometimes there are obscure requirements written into building codes that seem to be harmless or even beneficial, but whose object cannot be doubted when once their meaning and source are pointed out.

In the Pittsburgh Building Code it is required that built-up members used as girders shall be proportioned by their moments

*Structural Engineer, Robert W. Hunt & Co., Pittsburgh.

of inertia. This looks innocent enough. The specious plea is made that the moment of inertia is the proper function to use in designing a plate girder. The absolute fact is that it does not make any difference worth considering whether the effective depth and flange area be used or the true moment of inertia. But the crux of the matter lies in the interpretation of the term "moment of inertia". By the method of design using the effective depth and the flange area the net area of the parts is always used. This is the only correct way; no engineer would think of using any other. It makes the top flange unit stress less than the bottom flange stress, as it should be. By using the moment of inertia an engineer would also use the net section of the parts. He could not possibly be right any other way; his unit stress could not possibly be that which the ordinance demands, if he took the gross section. A commercial designer, however, is very apt to follow the lead of the makers of manufacturers' handbooks, from which this code is largely taken, and use the gross section.

The commercial designer can point to the manufacturers' handbooks and make the claim that these illustrate standard practice, but he can not show by any system of reasoning that the unit stresses of the code are not exceeded.

The Industrial Commission of the State of Wisconsin is working on a building code. They invited criticisms. The writer sent some. He recommended among other things, that moments on slabs and beams be straightly defined, that the rodded column be prohibited, and that dependence upon stirrups be forbidden. They answered that they want the code as brief as possible. Safe structural design they consider as subordinate. Not long ago 200 men just missed being killed in New York by the collapse of a theater that occurred just after they had left.

It is true that a building code cannot enter into every detail of structural design. It can, however, cover the broad principles of safe construction. The State cannot eliminate by law everything that has the element of danger in it. It can, however, prohibit the promiscuous use of firearms and explosives. A building code can prohibit the use of a plain concrete

column with a little rod in each corner, the thing that masquerades as reinforced concrete and has been the cause of more wrecks than would be produced by tons of dynamite. It could prohibit dependence on stirrups or so-called shear members, that have been second to the rodded column in breeding wrecks.

The Pittsburgh code allows the rodded column. It allows 90 lb. per sq. in. of shear on concrete beams, which is worse than stirrups.

According to a Chicago engineer we have the worst building code in existence, as relates to concrete columns; units from 1300 to 1800 lb. per sq. in. being allowed, which is just about the ultimate strength of our local concrete, as discovered by the Code Commission. From the results of the latest tests I showed recently (before the Am. Soc. C. E.) that plain and reinforced concrete columns all begin to fail at exactly the same unit stress. The hooped column holds together longer, that's all. Pittsburgh's building code allows reinforced concrete columns to be loaded to the point of incipient failure. This is the "safe" load.

The only thing that is any worse is the Joint Committee Report with their plain concrete columns and rodded columns with the rods held in with broom wire.

A good thing to write into a building code would be a requirement that curved girders must not support any load whatever. I recently checked a building where curved girders were expected to carry heavy loads; girders that could scarcely support their own dead weight. The Orpheum Theatre in New York had a great curved girder, 70 ft. in span, and with an offset of 12 ft. The thing flopped down and pulled the theater with it. And yet a large number of experts could examine that design with a straight face and never see the monstrosity of a girder that pulled it down.

Mr. Sidney J. Williams:* The proposition that state laws should be broad and capable of general application, leaving details and specific regulations to local authorities as much as possible, can hardly be controverted. This is true for two reasons. First, as Mr. Ferguson says, the state cannot properly

*Building Inspector, Industrial Commission of Wisconsin, Madison, Wis.

legislate on local matters. Second, state legislation on so broad a subject as the design and construction of buildings, cannot successfully be enforced except with the cooperation of local officials. Without such coöperation, the adequate enforcement of state building laws would require an army of state inspectors which would be obnoxious as well as very expensive. Now, to secure the cooperation of fire chiefs and other local officials who are not building experts, especially in the smaller cities and villages, the State Code must be broad, easily intelligible, and concise. Let me emphasize this statement. The State Code should be easily intelligible—that is, written in simple, "barn-yard English", without any great amount of technical detail; and it should be brief—that is, it should be confined to the essential matters of fire protection, sanitation and structural safety, rigidly excluding all non-essentials. By "non-essentials" I mean questions which do not arise in the smaller towns anyway and which in larger cities can be covered by the local code or left to the judgment of the fire chief or local inspector. Under "non-essentials" I also include the minute subdivision of classifications of occupancy and construction whose theoretical accuracy is overshadowed by the very considerable study which they require in order to be properly understood and applied.

Let this not be construed as a defense of superficiality, but simply as an argument for the proper consideration of the actual practical problems of enforcement, which, considered from the standpoint of *getting results*, are quite as important as the problem of drafting an ideally perfect piece of technical literature.

The point which I am trying to make is also demonstrated by the fact, well-known to common sense as well as to psychology, that the best way to interest a man in anything, is to give him something to do. The best way to interest local officials in the subject of building regulations, is to leave to them the task of working out detailed local ordinances to supplement the State code.

In Wisconsin the problem of working out a State Code which will be broad and brief without being superficial, is con-

siderably simplified. This Code (six copies of the tentative draft of which are sent you under separate cover) will be adopted, not by the legislature, but by the Industrial Commission, under the statute which provides that all public buildings and places of employment must be made reasonably safe. Since the Code is thus an instrument of the Commission, it can be altered or interpreted or special exceptions made, by the Commission at any time. As the Industrial Commission is not composed of architects or engineers, it will refer all technical questions to the committee of architects which drafted the Code and which will thus exercise the functions of Mr. Ferguson's Board of Appeal.

Though the powers of the Industrial Commission are thus very broad, they are at the same time strictly limited by the fact that any order of the Commission may be taken into the courts on the ground of unreasonableness.

Mr. Virgil G. Marini:* I have read with much interest Mr. Ferguson's paper and find his ideas on this subject afford material for very careful thought and discussion. The subject from all points, has been so well covered that I will confine myself to ideas which may be considered when reading this paper.

Taking Mr. Ferguson's suggested personnel of a proper Commission, which in my opinion is ideal, such Commission should start its operations by deciding:

First: Whether it is going to write a set of Building Specifications into law, or

Second: Whether it is going to control by legal measures only such features of building construction as will ensure for the occupants sufficient safety, light, ventilation, and sanitation.

The weakness of most building regulations is that they broaden into unnecessary specifications, and become so exhaustive and unwieldy, that under the most favorable conditions, with the most generous appropriation, the average Building Department can only hope to enforce about one-third of the provisions of its Code, and has no means of knowing whether the remaining two-thirds is being complied with, and if so, how.

*Consulting Engineer, Cleveland, Ohio.

This evil is more pronounced when one considers the repeated changes of Building Inspectors, due to politics, because a new incumbent in office certainly cannot enforce or control any more of the Building Code than his predecessor with greater experience, but the portions of the code the new appointee seeks to enforce are often sections never enforced by his predecessor, and sometimes the existence of these sections, because they have not heretofore been enforced, is totally unknown to the architect or engineer.

I succeeded, as Building Commissioner of Cleveland, an appointee who held the office for nearly six years.

The Building Code contained about 1100 sections and from the year 1904 when it became law, to the time I took office, 1910, very few amendments had been made for the following reasons:

First: Because no serious attempt has ever been made to enforce *all* these provisions.

Second: Because no effort was made to obtain sufficient funds for a large enough and proper department, those in charge rather nourishing the protection they secured by being able to say "I am enforcing as many of the building laws as I can with the staff at my command".

Laws enacted and not enforced are worse than no law at all, for (especially in building laws) lack of enforcement teaches lack of respect, and no law is easier to violate than one relating to building, since no law or set of laws can ever hope to regulate the many possible conditions in cases arising. Violations of building laws need not be criminal, and in many cases are not, since such violations may constitute another means of arriving at the same end.

I had many sections of the code amended and had more repealed, and while I am heartily in sympathy with Mr. Allen's earnest efforts to continue this work, I still fear that finally Cleveland will still have too large and specific a code, not all of it enforcible with the best possible staff, and worse still, the portions enforced by future Inspectors (which is likely, as long as politics control our civic pride) will possibly not agree with what had been enforced, so that, as in my time, the unsuspect-

ing architect will suppose that each new administration writes its own Building Code.

Reference has been made to the New York City Building Code. In April, 1912, a "Proposed Building Code for the City of New York" was prepared by a "Joint Committee on City Departments."

This Committee consisted of representation from the following organizations:

The New York Chapter, American Institute of Architects,
The Brooklyn Chapter, American Institute of Architects,
The New York Society of Architects,
The Building Trades Employers' Association,
The New York & National Board of Fire Underwriters,
The American Institute of Consulting Engineers,
and the seven Superintendents of Buildings.

In all thirty-three men of national fame in their respective professions drew up a set of building regulations for the City of New York of just 140 sections or less than one-sixth the size of the present Cleveland code. Materials not mentioned or covered could be used if they passed certain tests which were clearly defined, and this also applied to new forms of construction.

The reason for the failure of the passage of this excellent code was due to just one thing, "politics." It was put in the hands of an Aldermanic Committee, and this committee died a political death before it could undo the excellent work of the New York architects, engineers, etc., and Mr. Rudolph P. Miller, who has temporarily resigned as Superintendent of Buildings, Manhattan, for the next three months will devote his time to re-compiling and completing this work.

The writer was a member of a committee of six at the National Fire Prevention Convention which drew a resolution to the effect that the words "Fireproof" and "Incombustible" be omitted in the future from the vocabulary of Building Codes and the words "Fire Resistive" used instead.

This resolution was unanimously adopted and led to the enactment of the proposed "Standards in Fire Resistance" by the Executive Committee of the Gypsum Industries Associa-

tion, composed of active members of the National Fire Protection Association.

I am glad Mr. Ferguson has referred to these Standards in his Tables Nos. 1, 2 and 3, because I feel this is the only scientific and fair method of approving or rejecting any building material when such materials are used to protect a building against fire. Building Codes should avoid mentioning specific materials and methods.

The Standard Tables, to which Mr. Ferguson refers, are to be desired for the following reasons:

First: They place each and every material on test and merit for whatever purpose or place such material is to be used.

Second: The fire protection of buildings, now not fire protected, is encouraged by gradation according to requirements into three classes of protection, "Full," "Partial," and "Temporary."

Third: Such tables can be expanded or reduced according to the requirements of the state or city.

To view the writing of building laws from another extreme, brevity could be secured by stating about as follows:

All materials entering into construction for their various uses, shall comply with the requirements of the American Society for Testing Materials, etc., of a certain date.

No materials shall be used in fully protected fire resistive buildings which has not the approval of the National Board of Fire Underwriters, or the U. S. Bureau of Standards, for such purposes.

Steel work and steel construction shall comply with modern engineering practice and the standards of the American Bridge Co. as set forth in their book of a certain date, etc.

Of course the legality of such wording may be questioned, and I have used perhaps an extreme illustration of simplicity in building code writing, but from my experience in cases which found their way to the courts, often the actual provisions of the code, right or wrong, were forgotten and the court and jury confined themselves and decided the case on the testimony of experts who based their views on modern engineering customs or practice.

So the following procedure might be suggested:

First: Make your legislative requirements, drawings, stress sheets and diagrams to be submitted as severe as possible, because the incompetent architect or engineer cannot supply proper stress sheets, etc., without proper help.

Second: Have full and complete definitions.

Third: Classify and grade all kinds of buildings.

Fourth: Control the use and occupance of such buildings for various purposes.

Fifth: Provide regulations for occupance of lot,
Height of Building,
Area of undivided spaces,
Light and ventilation,
Ingress and Egress (Stairs, etc.).
Sanitation.

Sixth: Define loading on soils.

Give maximum stresses of various natures allowable on all the metals, also on various timbers, stones, concretes, etc., etc.

Seventh: Regulate Elevators, Gas, Electric Wiring, Boilers, Furnaces, etc.

Eighth: Define the "Inner" and "Outer" fire limits.

Ninth: Control the area, height, etc., of the following classes of buildings within such fire limits.

Fully Protected Buildings (Fireproof, so-called).
Partially Protected Buildings (Composite, so-called).
Temporarily Protected Buildings (Composite, so-called).
Combustible Buildings (Frame structures).

With reference to a "Board of Appeals" too much stress cannot be laid on the importance of this Board since all appeals cover questions not covered by the building regulations, the use of new materials, and a difference of opinion upon the judgment or ruling of the Building Commissioner.

The membership of the Board in the State of Ohio and the Cleveland Building Codes is composed of members of the Cabinet, usually of the same political faith as the Building Commissioner, and if not, then affiliated and in sympathy with the Building Commissioner by virtue of holding office under the same government.

This should not be the case. I have remonstrated and advised, so far in vain, that all Board of Appeals should be composed of experts in the necessary professions, appointed by the

Architects, Engineers, Builders Exchange, and such associations that are free from politics.

The expense of such services could be met by proper appropriation, or by a fee for each case which would be paid by the party losing same.

In a paper read before the Cleveland Engineering Society on November, 1912, I showed that the Cleveland code was inoperative and unenforcible in about 60 percent of its provisions because it was a conglomeration of laws, ordinances and specifications, too voluminous and ambiguous in many of its 1100 sections, and positively contradictory in about one-third of these.*

The Ohio State Building Code, following the lines of the Cleveland Code, is entering upon the same error, viz., writing a specification rather than a legal building condition.

In December 1911 issue of the "Ohio Architect", under the title, "An Un-enforcible Code", the writer endeavors to show that the requirements of the State Code were impossible of enforcement, for the State will never have the funds to create an inspection department of sufficient size to carry to completion the requirements of a State Law on Buildings which in truth is a specification and text book.

The Illinois State Building Code is a leader in sensible requirements and legal brevity, and when I asked a member of the Commission how they confined themselves to such concise brevity when elsewhere "*quantity and not quality*" seemed to be the slogan, he replied "Well you see we license all our Architects and Engineers in this State." In writing Building Laws we attempt, to too great an extent, to educate and advise the incompetent architect and engineer.

A building law instead of being concise and to the point, becomes a specification with explanations, reasons, etc., and so often loses its force when tested in a court proceeding. A building law should only attempt to govern and control the vital principles I have covered, seeking to protect life and health, this being done the real protection lies in the State assuring itself that only competent professional men engage in

*Journal, Cleveland Engineering Society, v. 5, November, 1912.

the design and erection of structures, and this can be done, as in the State of Illinois, by license to practice.

Secure brevity in Building Laws, eliminate building departments from political appointments or changes, create outside and non-political Appeal Boards, license architects and contractors, and remember that a brief building code covering vital features of safety and sanitation, all enforced to every one alike, all of the time, is far better than an unwielding document of laws and specifications, only part of which can be enforced, such portion changing at the will of the Building Commissioner, depending on his feelings political or otherwise.

Mr. Richard E. Schmidt:* I agree with Mr. Ferguson that one of the most important requisites of a satisfactory code is that the Architect, Engineer, Contractor or owner shall be placed in possession of all necessary information, to enable him to build without official interference. He has also stated that it should not be so definite as to be like a specification, but that it should be elastic. If it is not definite much time will be consumed in obtaining decisions and a great variety of decisions are likely to be rendered, so that we will eventually have the same state of conditions as exist today; that is, that materials are accredited with greatly varying safe stresses in different cities of the same state.

I am of the belief that it is necessary to draw an ordinance quite definitely almost in the manner of a specification, so that, at least the cities of one state will conform to the same law.

The requirements of existing building laws in different cities vary greatly, many of them must be illogical or based on fallacies, the required minimum live loads in pounds per square foot is 125 for an assembly hall in Boston, and 90 in New York; 70 for dwellings in Philadelphia, 40 in Cleveland and so on through the entire list of buildings. Safe unit stresses vary in the same proportion in different cities and accidents do not appear to have resulted from the use of low unit loads or high unit stresses, but they have been due to defective workmanship or faulty design.

Unnecessarily high floor load requirements and low unit

*Architect, 104 S. Michigan Ave., Chicago.

stresses are wasteful of material, not in accordance with the general desire for conservation of our resources and one of the causes of the high cost of living.

Building of like occupancy both in character and extent contain within themselves the same elements of danger to the occupants, regardless of location, whether in one community or another, and should therefore be subject to like codes or at least the same basic code.

The manufacturer who is obliged to spend more money in the construction of his building than his competitor elsewhere, on account of a more exacting code, is naturally at a disadvantage and is subjected to unequal competition.

The broadening of a definite detailed ordinance can still be left to the work of a permanent commission, who, in turn, must make their recommendations to the governing authorities of the city.

I cannot concur in the representation on the commission recommended by Mr. Ferguson. I base my view on my experience as a member of two commissions and the chairman of a third.

Four or five of the representatives recommended by Mr. Ferguson must be classed as laymen, real estate dealers, physicians and contractors may be big hearted and broad minded but they lack the experience and training necessary to grasp and coordinate all of the elements which must and do require consideration in the drafting of a building law; it is technical work and can be properly consummated only by technical men.

I agree most earnestly with Mr. Blackall's advice to your Mr. Stotz. It will be difficult enough and real estate interests, medical societies and builders associations should be asked to review and criticise a tentative draft before a final draft is delivered to the legislature or board of aldermen.

Two architects on a commission of eight members is too small a proportion. It should have more architects and structural engineers, in order that the weight of technical opinion will be on the side of the building experts.

The reason for this contention lies in the fact that the profession of architecture is the only profession that is compre-

hensive in the scope of its work, to require a thorough working knowledge, perhaps only though of a general nature in some cases, of all the subjects covered by a building code.

In my experience on commissions I have found but very few men who have constructive ideas for ordinances, or the willingness or ability to place ideas into tangible paragraphs, and too much time is consumed if the attempt is made to teach a lawyer to understand all of the technical phases of a subject under discussion. Of all the men suggested by Mr. Ferguson, this work will devolve on the Architects and the Structural Engineers and when each is in his own little study, not in committee meeting. The remaining members of commissions give the matter little thought between meetings and criticise and destroy the work of the working members. They undoubtedly render a service in finding flaws but it is unfair to the other members to virtually force them to perform all of the work or to see it suffer in quality or by delay if they do not do it.

At the outset a working agreement should be adopted to carry on the work somewhat as follows:

After a general discussion, exchange of views and an agreement on the essence of a particular subject, a small portion of work should be allotted to each member at the close of each meeting, with the understanding that he is to develope the paragraph or paragraphs into appropriate form for further discussion and adoption at the following meeting.

Those who consistently fail in the performance of their share of the work should resign and their places should then be filled by more promising experts.

Men of large affairs too busy with their own interests to give much time to the work are not desirable members; they are more likely to be representatives of special interests and should not be permitted to burden the active willing workers with the whole load and rob them of a part of the time they must devote to the gaining of their livelihood.

Mr. C. H. Blackall:* Absence from the city made it impossible for me to give proper attention to this very interesting paper. I can only say now that the paper is admirable in every

*Architect, 20 Beacon St., Boston, Mass.

way. I am especially glad that the paper recognizes the desirability of a Board of Appeal. The Board of Appeal has worked admirably here for many years and it does away with the necessity of making the Building Law a specification, a condition which has worked so disastrously in connection with the Chicago, Cleveland and New York laws.

I would suggest one small point which affects a class of buildings with which I have had considerable experience. The definition given for a theater might be dodged a little bit in practice and I should think it would be advisable to say that it would include any hall designed for or used for the entertainment of spectators, *seating more than* 300 *on any one level, or with more than one balcony,* and having a permanent or temporary stage upon which stage scenery and theatrical apparatus *might be employed.*"

Mr. J. C. Wilson:* I quite agree with a former speaker in regard to the Building Inspector's office writing the Code and then submitting it to a commission as he suggests, made up of the Engineers' Society, the architects and master builders associations, or the builders exchange or whichever it may be.

The Author: Mr. Godfrey says that "The prime object of a building code is to insure the building of safe structures to the end that life and property be conserved." I am quite sure we will all agree heartily with this statement.

It would be one thing to sit down and write a model building law and it is quite another, to attempt to listen to all and try to fit their ideas into one law and have anything fit to be a guide to designers when the work is done. A building law is not a text book to teach inexperienced, untrained men how to do their work correctly. If a building law is to be kept consistent, it should only state general requirements which are the limit of safety and omit anything which has a tendency to tell an engineer how to do his work, or what he must do to make his work safe. His training and experience should teach him this.

To this end then let us plainly understand that if one engineer wants to use any method of calculating the strength of

*President, A. & S. Wilson Company, Building Contractors, Pittsburgh.

plate girders which appeals to him, by all means let him do it that way, whether it be my way of areas of flange angles or moments of inertia, provided however, that when he is done his work may be checked and found safe; but if any one else has another way to do it, let him have his way also, if his work is then safe. A building law has no business meddling with the details of his method, even if he wants to place vertical stirrups in a beam or rods in a column, or if he has any method of construction which is an improvement, then by all means, do not hinder him. First let him prove the safety of his method of construction and the correctness of his theoretical assumptions and calculations by conducting tests on a real structure and checking back his theories to fit what is thus ascertained. If a test on a construction proves that it has a proper factor of safety, then it makes no difference to any one else what his theory has been, the structure is safe and that is all there is to it.

A careful study of the ordinances passed by the recent commission will disclose all these principles plainly and tersely stated. Any one wishing to employ a special mode of construction must prove its safety by testing it to the satisfaction of the building inspector, furnishing his specifications and proving that it has a safety factor of four. An additional requirement is then that the unit strains set down in the ordinance are not to be exceeded. This is the way the inspector interprets the clause "and satisfactory to the Superintendent."

After having applied the column formula given in the concrete ordinance to some of the heaviest loadings that have ever been placed on a reinforced concrete column I have never been able to discover that a unit stress higher than 1300 lb. per sq. in. would be allowable. Where the stated limits come from I know not, as no such unit stresses have yet appeared to be allowable on columns that can be built. I should like to have Mr. Godfrey show how these calculations were made.

It might be a bit of information to the members of this Society that the tests recently conducted on life size columns right here in Pittsburgh show that a unit stress of 1300 lb. per sq. in. is perfectly safe if one can expect reasonably good work-

manship and the standard quality of materials. These tests were conducted under the auspices of the Concrete Institute at the Pittsburgh Testing Station, U. S. Bureau of Standards.

In the paper it was intended to state what should go into a building law, in order to have it closely approach the ideal. Of course, it will be understood that no work of such a kind will be done in an ideal manner. The standard of excellence of any law will be lower than that which I have tried to set up in the paper. However, this much is true, that it is possible to improve very much on present conditions.

This subject is one that requires almost a lifetime in study. I could call your attention to many phases that would not, at first glance, be considered a part of the work of writing building laws. I will mention a few.

First, is the general welfare of all individuals in a community from the standard of living down through considerations of its expense, the general health, safety and morals. Much of this work, true, must be done by those devoted to welfare work, but many parts of building law have a bearing also, as especially in workingmen's houses. If individual houses can not be obtained at a price which a workingman can pay, he will have to be huddled in crowded tenements. You can readily imagine what must be done in this matter before building laws will be perfect.

Second, as to districting cities: Pittsburgh is peculiarly situated. River fronts are needed for shipping facilities, both by rail and boat. Factories can be placed there. The surrounding hills, very barren of vegetation or use of any kind now would then become the proper place for the homes for the operatives and they could be made sanitary at small expense as rainfall carries much off a hillside that lies and rots on a level. By districting in this manner, the poor man's house may be constructed to resist a decreased fire hazard since he is not endangered by the big fire risks. By the use of non-inflammable building materials all risks are reduced to a minimum. Thus the protection against fire need not be as elaborate or cost as heavily. The principal expense then would be merely for pro-

tection against cold and the weather. Many other matters affecting the business of our town depend on this subject alone.

Third, comes the matter of the building inspector making studies to find ways and means for bettering the housing conditions of the community in all ways possible. He should be active in promoting all work of this kind.

Now, as to the various detail questions which have arisen in the discussion, there is one which calls for especial attention. In my heart I agree with what Mr. Allen has about the Building Inspector having an especial knowledge of the matter which would qualify him especially to assist in writing the building laws. However, it is necessary for him to be capable of performing the work. None but carefully trained, broad gauge men should undertake this work.

Again, there is a theory of democratic government that those charged with the administration of laws should not be charged with their making. This may be gotten round in the manner in which Mr. Allen said it has been done in Cleveland by having his work checked by others, or by making the building inspector a member of the commission so that they may take advantage of his especial knowledge and to put him in a fighting position.

MINE VALUATION

By J. R. Finlay*

In my experience I have had occasion to put a value on mines for four different reasons. First, for the purpose of a prospective purchaser. Second, for the benefit of casual investors. Third, to make comparative valuations of mines for the purpose of consolidation. In that case, of course it would not matter what your basis of valuation was as long as it was fair to both sides. And fourth, to serve the purposes of a Tax Commission.

In all work that I have done I have worked on one theory, which was propounded, I think, by Mr. H. C. Hoover: That the only value to be put on a mine must come out of its expected earnings. In other words the value is simply the capitalization of its earnings, as they will appear in a series of dividends. This applies to properties that are not equipped, as well as to those that are equipped, for actual mining. By this theory a plant at a mine adds value to the property simply because it enables it to earn more money than it would if it was not so equipped, and hastens the period of earnings.

I have discovered that most owners, and particularly most bankers, do not get this point of view exactly. When you are asked by a banker to put a value on a mining property you are usually asked to be specific about three things, first what the liquid assets are, second what the equipment is worth, and third what the land is worth. As a matter of fact it often injures no one to divide the value of property in that way. If property is worth $1 000 000 it does not injure any one to say that $100 000 of it is liquid assets, $400 000 in equipment and $500 000 in land; except in this way I would figure that if a property could not earn any dividend it would not be worth one cent even if it

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had a million dollars worth of equipment on it; because I do not know of a single instance in which mining equipment which does not serve the purpose for which it was made ever yielded enough as junk to pay the expense the company is put to in taking care of it.

Therefore the theory is that the capitalization of expected earnings is really all that we have as a logical basis for valuing a mine. Of course that does not apply to liquid assets. You might have a certain amount of coal, or iron, or lead mined, or anything that is salable, or cash in bank. That is a different thing. I mean the solid property, the equipment and the lands. Whether that theory is right or not, it is the only one that I have ever worked on, and if I am not very much mistaken it is the one that is generally accepted by mining engineers today.

The casual investor has a right to buy shares in a mining company with reference to three factors:

First: How long the property will last.

Second: How much it will pay annually.

Third: How much his money is worth if invested without trouble to himself.

The investor who is responsible for a mining enterprise has a right to demand a return for himself on different grounds.

First: He must risk money for development which will assure a given life.

Second: He must embark in the enterprise an amount of money which is risked simply to make it safer for others to put in money. He is entitled to be paid for taking this risk.

Third: If he finances his property with his own money, he is entitled to a return on such portion of it as he might secure from others equal to what he would have to pay others for it.

Fourth: After reimbursing himself for his enterprise and risk in the above respects, he is entitled also to such ordinary returns on his investment as he might get for his money, if he took no risk.

While it is difficult to take the measure of these factors in a generalization, it is only by weighing them that we can arrive at the price which should be put on a property by one who contemplates buying it.

The point I wish to bring to your attention especially is the difference in the situation of a casual investor in mining

stock and that of a man who shoulders the financial and technical responsibilities of an enterprise. It has been brought to my attention very forcibly that the man who is responsible for a mine faces a situation quite different from that which I have usually had in mind in putting a value on property. The casual investor, if he has any sense, usually buys into a property that is thoroughly established. It is already financed. The management is settled. It is already producing something. All he needs to do in order to know whether he wants to buy shares of that property is to get information on these three factors. Of course if he has no means of finding out the truth about these factors he is all at sea. But if he knows how long a property will last and how much it will pay annually, it comes down to a simple question of how much he can get for his money in an investment which gives him no personal trouble. That I think is usually found to be somewhere around 5 percent.

I am really at a loss to know whether all the members of this Society have followed the subject of the valuation of mines or not. Perhaps I had better stop here and explain one or two things for fear some of you may not be at all familiar with the subject. When I speak of money being worth 5 percent I mean that as net interest. It is a perfectly safe thing to say that no one has any business buying mining stock which does not yield over 5 percent dividends. But I mean this, that if you can get 5 percent net in the form of interest merely for the use of your money, if you do not lose anything, you do about as well as you can ordinarily do. But of course a mining property being a property of limited life, the buyer must apply the first factor, namely, how long the property will last, in this way: He must figure on a dividend sufficient to pay interest on his investment and also to amortize his capital within the life of the mine. I do not mean that it is necessary for him to build up a sinking fund. The investor generally does not do that. But he must figure on a sufficient return to create a sinking fund which will pay back his principal as well as his interest. I have no tables of amortization with me, but I can recall roughly some figures. If a property will last 20 years and you expect 5 percent interest on it, you must set aside a sum of about

3 percent each year and invest that at 4 percent and keep investing it each year and reinvest the returns of that for 20 years in order to pay back your principal. In the mean time each year you expect 5 percent interest, so that a property with a 20 year life should give you dividends equal to 8 percent at least on the price you pay for it. If it is going to last only ten years the least dividend that will possibly justify your investment is 15 percent. If you increase the life to 40 years the least return that is adequate under any interest rate is about 6 percent. I do not undertake to give exact figures. But the point where the interest rate on money influences the valuation of a mining property is that your imaginary sinking fund has to be added to your rate of interest. Thus if you require 6 percent interest on your money and the life of the mine is to be 20 years the least return that will do you any good will be 9 percent. If you need 7 percent on your money you must have 10 percent on a property that will last 20 years.

I imagine that people in the Pittsburgh District are mainly interested in iron and coal properties. Therefore possibly these considerations are more evident here than they would be in most places. I take it for granted that as coal property can usually be figured on pretty accurately as to life, there should be no great difficulty in estimating the amount of coal that can be obtained per acre, and if you have a property of 1000 acres and you figure on a plant that will put out so many tons, then you know what life to figure on, and you also have an opportunity to figure on the most profitable life for a given acreage. The sooner you get the profits the better, unless they are obtained at the expense of too great an initial investment.

But I have been speaking of the rate the casual investor, the man who takes no personal responsibility, expects. As a matter of fact I have found out that the best way to learn what money is worth is to borrow it. If I am not very much mistaken a great deal of coal mining is done on borrowed capital, therefore I imagine that I am talking to some people who will appreciate what I have to say. Owing to the usual limit of life to a mining property, it is generally necessary to borrow money to be repaid within a limited period, a few years. There-

fore the rate of interest that is really applicable to the business is usually the rate of interest that applies to short time note issues. Now the bankers will put out a note issue say for \$1 000 000 with let us say a 4 year maturity, at 6 percent interest. On the face of it you might suppose that a mining property which sells these notes only pays 6 percent interest. That would be \$60 000 a year. But as a matter of fact you must remember that the banker has to be paid himself. You have to pay him a good round sum for his activities in securing this money for you and for guaranteeing it. Under the present market you will do well I think with a coal property to be able to sell short time notes at less than about 12 percent discount. On the face of it perhaps the discount would be 10 percent, but the banker always makes you pay for everything he does. He makes you pay for his lawyers who examine your title, his mining engineer who examines your property, and usually throws in a little for himself. And then he insists on a little graft that lasts quite a while, for instance on your paying a mining engineer that he nominates to watch your own property for you for four years, and you pay him a good big salary, too, when you consider that he does nothing, \$5000 a year is a usual figure for that kind of graft. And when you get down to brass tacks you will find that you have obligated yourself to pay \$1 000 000, of course after four years, and you have received say \$880 000, and that means that you will pay 6 percent on \$1 000 000, or \$60 000 a year, and \$120 000 besides, which brings it right up to 9 percent immediately.

The point I have thought of recently is that really, in justice to himself, a man who is going to take the responsibility of operating a property should allow himself as much interest as he would have to pay anybody else for the use of that money, and in good, square, common sense he should have more, for this reason: A banker will never lend him money at all unless the entrepreneur, or the man that starts the enterprise, has already put in some of his own which helps to guarantee the property and make the security for the banker. He is taking much larger risk than the banker is, and if he had to pay the banker for taking such a risk there is no telling what rate of interest and discount he would have to pay.

So I have put down here a list of the things he must do. Suppose he starts in on a property that has a showing which is enough to start with, enough to warrant him in believing that he can start the property. I do not know much about the coal business, but let us have an imaginary coal mine. Our operator knows that in this Pittsburgh region we have at least one and perhaps two seams of coal within a certain area. Suppose he figures on buying a tract of land on which to start a coal mine. He would have still to do some testing and drilling or exploration to make sure just what the condition of that seam is on the particular property that he is contemplating. He would also have to go to some expense in having the title looked over by lawyers, and quite a bit of preliminary expense. That he would absolutely have to risk. If on the strength of that he decided that the property was worth going ahead with, then he must begin his investment in the plant. Now before he gets to the point where a banker would lend him money on his enterprise he has got to put in a great deal of money himself. I claim that on that amount of money which is necessary to put the enterprise in such a position that a banker will take it seriously. the projector of such an enterprise should expect a larger return than the banker would expect on his money.

I have already proved, as it seems to me, that you can not borrow money on such a property as that for less than a net outgo of 9 percent interest on the money you have borrowed, therefore it seems to me that the projector of an enterprise should allow himself considerably more than that for what he puts in. How much more I do not know. But I should say that if a man put $1 000 000 into a property in order to get it in such shape that he could borrow another million on it to complete it, it would be not at all unfair to expect twice as much interest, or discount, on the first million as he would have to pay on the second, because the risk is proportionately greater.

If we make such an assumption as to the value of money we would arrive at a figure something like this for the whole $2 000 000 required. He should expect an interest rate of somewhere around 14 percent, being the average between 9 and 18 percent. That of course is on money invested for a compara-

tively short time. Further the investment will be a failure unless he figures on earnings sufficient to create a sinking fund which will pay back the whole investment during the life of the property. As nearly as I can figure roughly the absolute interest rate should vary according to the life of the property. If these suggestions as to the value of the money are really correct, if we suppose the property has a very limited life, say five years, the projector of an enterprise should expect at the very least to set aside 20 years for the return of his capital and then he should be satisfied to expect 13 percent profit, so that a mining property which cost $2 000 000 to start and had five years life ahead of it should pay back in dividends something like this: $400 000 a year for the return of capital and 13 percent on that capital, or $260 000 more. It should pay 33 percent interest to the projector in order to give him just a running chance, just a moderate chance for profit, the kind of profit that the banker gets any way—that he is compelled to pay to other people whose money he uses.

Of course if the life of the investment is very much longer he would perhaps be able to spread his discount over a longer period and the rate would be somewhat less. For instance if we imagine the life of this property to extend to 20 years and you can borrow money at the same rate of interest and the same discount, the man who borrows the $1 000 000 would have to pay $60 000 a year interest and the discount he would have to pay to the banker would be $120 000 and you could spread that over 20 years, and it does not add very much to the interest rate. His real payment then would be $66 000 a year or 6.6 percent. But I think it would still be true that the projector of the enterprise should have a larger rate of interest on the money required to make it worth the banker's while to lend him money. So that I should put it down as a sort of a generalization that no one is warranted in taking the financial responsibility of a mining enterprise unless he can figure out for himself at least 10 percent net interest on all the money he invests in it. So that even with a 20 year life I should think the projector of a mining property would be doing poor business unless he could figure out for himself a dividend of at least 13

percent a year. Of course as a matter of fact most successful mining properties pay at least that much on their original investment.

But here is a point that I have wondered about, whether in considering the value of mines for the purposes of taxation a state cannot afford to allow to the companies, which own these mines and have operated them, an interest rate equal to that which should be allowed to an investor who is thinking of opening up a mine. I do not know about that. I am inclined to think it should, that in fixing a value for property for taxation it would be fairer after all for the state to make a fixed rule to allow 10 percent interest on the investment besides an amortization amount.

DISCUSSION

Mr. W. E. Fohl:* We of Pittsburgh have been chiefly concerned and are best acquainted with mines producing coal, either for shipment raw to more or less distant industries or for the manufacture of coke in ovens adjacent to the mines, which process of manufacture is of necessity an integral part of the investment proposition.

These mining enterprises have, for the most part, attempted to reach Mr. Finlay's "casual investor" by bond issues intended to present an investment without trouble to the investor and paying a sufficient rate of interest to make them attractive when compared with other industrial security issues. The essentials of a proper valuation on which to base these bond issues have been given in the early part of Mr. Finlay's paper, but their concrete applications present some intricacies.

Such a valuation, though, is not a safe one unless there is taken into account the broader one which comprehends the entire operating life of the mine and which requires the capitalization of its prospective profits. We must admit that any attempt at calculating such a value is precarious; we cannot see into the earth and discover the irregularities in the deposition of minerals; neither can we foretell the vagaries of either our labor or our consuming market. However, there is no busi-

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ness without risk and the appraiser of mining properties must assume his share of it in order that there may be some finger board to direct the investment of capital.

As a basis for comment I present in the simplest possible form a calculation of the probabilities of operating to exhaustion a 400 oven plant mining Connellsville coal and manufacturing coke in bee-hive ovens, the seam producing 8000 tons of coke per acre and the mine having a productive life of 40 years:

INVESTMENT:	
1000 Acres land @ $1500	$1 500 000
400 Ovens @ $1200	480 000
Total	$1 980 000
Annual interest on capital	118 800
Interest charges per ton of coke produced (500 tons per annum per oven)	59.4c.
Amount to be invested at beginning of every half year at 4% interest compounded semi-annually, to extinguish entire capital in 40 years	$10 018.80
Sinking fund charges per ton of coke produced	10c.

Carrying the calculation a little farther, the total cost of coke production per ton would appear as follows:

Mining of coal and manufacture of coke, exclusive of capital charges	$1.50
Interest on capital	0.594
Sinking Fund	0.10
Total	$2.194

Revenues from rents and merchandizing, figures for which are not at my command, are properly deductible from this total cost and the calculation does not otherwise purport to be an exact representation of coke region conditions. Nevertheless, it is near enough to make the prospective investor hesitate when he considers how nearly it approaches the average selling price of coke when it is calculated for a period of years and to warn him of the necessity of close figuring on all coal and coke propositions.

If, however, exactly the same plant were used to exhaust a tract containing only 500 acres, while the sinking fund charge would be increased to 20 cents, the interest charge

would be reduced to 36.9 cents, making the total capital charges 56.9 cents instead of 69.4 cents as used in the calculation.

All this may seem to be a trifle elementary, but it appears to be overlooked by those who seem to be able to see no limit to acreage prices for coking coal and it certainly requires consideration by consumers of coke who must, by payment of reasonable prices for their consumption, help carry the charges for capital already invested in plants and coking coal lands, or else supply will be cut off by failure to produce.

To arrive at the prospective profits of the operating investor such a calculation as the one above given must be carried a step further and the present worth must be determined of the difference between the cost of production and the average selling price over a term of years. At the best, though, such a calculation can give only a very general idea of actual value, being based on an average cost of production and an average selling price of the product, both of which must be applied to any particular property with great discrimination.

I believe that ordinarily a more nearly correct idea of purchase values may be obtained by a capitalization of current royalties, and that this method of arriving at a proper price to pay for coal lands is especially suited to regions in which there has been insufficient development to determine a reliable average figure either for cost of production or selling price of the product. Royalties seem to be able to travel over considerable stretches of country without change and a royalty figure once fixed in a locality displays an extraordinary resistance to change. Adam Smith in his chapter on "The Rent of Land", written more than 130 years ago, says that in coal mines a fifth of the gross product is a very great rent and a tenth, the common rent. These proportions obtain still in the United States almost without change, the very great rent named by Smith being current in the Anthracite and Connellsville regions, and the common rent generally elsewhere in the coal producing sections of the country.

Mr. George S. Rice:* I hesitate to attempt further discussion of a subject broached by so eminent an authority as

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Mr. Finlay. As a matter of fact when our energetic secretary called me up by 'phone to ask if I would say something on the matter, I improperly jumped to the conclusion that the subject of valuation of mines referred to their valuation for taxation purposes, perhaps this was not an unreasonable conclusion as in this field also Mr. Finlay has made his mark as an authority. Probably no more prodigious task was ever undertaken by a mining engineer than to value all the great iron and copper mines of Michigan in a few months. This he accomplished in a manner which on all sides is recognized as a magnificent piece of work. Not all mine operators agreed as to the result of the individual valuations of their own properties but some inequalities are to be expected as manifestly it was physically impossible for Mr. Finlay to personally examine with thoroughness each mine and the mine records. he was of course obliged to rely on his staff and to pronounce on the general principles governing valuation. That there has been complaint from so few operators shows how well the gigantic task was accomplished of equalizing the taxation on Michigan mineral properties.

Of course, not all will agree with the principles laid down by Mr. Finlay, but I have heard a number of mining men who did disagree admit that with a very few exceptions the equalization of taxes had worked out remarkably well.

While this in a measure is not speaking strictly on the subject in hand, yet I think it is so related and I have so much personal interest in it that I will venture to speak of a phase in the Finlay system of valuation for taxation that I have much question about in my own mind, namely, in basing taxation values not only on mineral already blocked out but upon future expectations. I will not attempt to cover this ground in detail but will point out what I consider its great disadvantages form the standpoint of the welfare of the mining industry. The following statements are those on which I base my arguments.

First: That the state, county and township are entitled to receive support through taxation from the mining industry proportionate to the benefits conferred and proportionate value of the mineral extracted.

Second: That it is to the interest of the state, even more than the nation, that the mineral industry within its borders should be fostered and developed as much as possible, and, so far as nature permits it, should be placed on a permanent basis.

Third: To secure the latter desired result that prospecting for new ore, or mineral bodies, and the development of reserves should be encouraged.

Fourth: That mineral as long as it remains in the ground is intrinsically without value.

Fifth: That neither the cost of underground improvements nor of mining plants, that is, machines and structures which are needed for the extraction and local concentration of the ore or mineral should be taxed.

On the first four propositions most of you will agree, but on the last many will not. My argument concerning it is: That shafts, levels, or other underground developments are in themselves of no value if the mining property fails, or if the mineral is exhausted, but even if the exploratory workings do not find valuable mineral, that is, profitable to mine, the information obtained is of value, though negative, and hence it is of value to the state in determining where development should be encouraged. The same argument is in part true of the surface plant though not wholly, as when the plant is of cheap construction, since there is then little salvage value. Even the plant may have salvage value, nevertheless I venture to make this assertion that it is of greater value to the state and community that the improvements be of high character for the purpose of giving greater safety in the prevention of accidents from fires, hoisting accidents and the like, than for taxation purposes. For that reason I do not think such improvements should be taxed.

This brings me to the gist of my contention shadowed in my fourth proposition, namely, that taxation should be based on mineral when it is brought to the surface and sufficiently separated from the vein rock to be transportable commercially. With ordinary iron ores this would mean merely sorting or washing; with gold, copper or other ores, the first concentra-

tion; with coal, picking and washing. I therefore propose an output tonnage tax with the thought that this will be the most equitable way of taxation.

In France, the theory that mineral is without value until brought to the surface, has long been acted upon. Concessions for coal, for example, are granted formerly by the crown, now by the state, for a nominal annual consideration of about 50 cents per acre; the chief tax is received through a royalty determined by a percentage, 5 percent, of the net annual profits before dividends or investment interest is paid. Where the profits in coal mining have been almost uniformly high, as they have been in France, 25 cents to $1.00 per metric ton (2204 pounds), this plan appears to work well, but would hardly be suited to the variable profits or absence of profits of the mining business in this country.

I think that taxation of mineral in the ground is frequently very unfair. For example, in Illinois and other states, the coal rights which have been purchased as such are immediately taxed. The farmer whose land may be surrounded by these purchased rights does not have his land assessed on the basis of being underlain with coal, although it may be known through drilling that the tract does contain coal. It may be argued that such coal rights are bought up to control the market, but it does not appear plausible to me that men, or group of men, are willing to invest large sums of money and not open out a mineral property when there is a real demand for coal output and willingly lose the interest year after year on this investment. But even granting that, I believe that a situation of this sort could be met by the state taking possession under condemnation proceedings with proper valuation and compensation and then leasing the property. I believe no one has a right to withhold in the case of real need of a community a natural basic resource, but the owner should be compensated as is the man whose land is condemned by a railroad.

To further support my view that it is not advisable to tax mineral reserves in a mine either blocked out or prospective, I believe it restricts the underground development which all mining men consider wise, I will cite, without nam-

ing the mine, a case in Michigan where a question involving caving of the surface brought me into it, as a matter involving safety of life. In this case the quantity of ore to be taken out in future seemed involved, upon inquiry the management of the mine stated they did not know how much ore did exist below the working level in question, and I have no doubt they spoke the truth. It naturally occurred to me, why in so large a mine operated by a company with strong financial backing they were not blocking out ground for a couple of years ahead or at least drill core drill holes ahead. The answer seemed to be that they did not want to know, that they might be penalized by taxation if they did so.

Again, let me cite the case of a coal company in the middle west with which I had personal acquaintance. The mine was physically a good one and had an equipment far above the average, unfortunately certain changes in railroad ownership and a general stagnation from over development of the coal mining business turned what had been a good paying property into a losing one. The chief owners would have been willing to shut down and wait, but the taxes on the coal in the ground and on the fine surface plant, like the stabled horse, made it "eat its head off". The state got its taxes for a few years then the mine was wiped out of existence, which was not good for the community or the state.

It is not argued that the tax on the mining industry, as a whole, should be lessened but rather that it should be borne by the producing mines according to their output; and for the same kind of mineral should be alike just as are, roughly speaking, the transportation charges which make a far larger proportion of the value at the marketing point are alike or theoretically so for the same kind of mineral from the same district going to the market.

Now to briefly reply to Mr. Finlay's questions, for not knowing his answers in formulating these remarks, I may find that I am in entire agreement.

First: The casual investor should be informed how long the mineral will last as nearly as this can be determined. In the case of coal, the quality should be determined within a

reasonable degree by preliminary drilling and the investor should then be informed of the prospective output as nearly as this can be calculated in advance.

Second: He should be informed how much the property will pay annually so far as this can be predicted by a competent mining engineer.

Third: For a mining investment not involving so much speculation as to quality and value as in coal, iron and disseminated copper and gold ores 10 percent per annum plus the annual or final return of principal should be expected. In more speculatively hazardous mining 20 percent annual seems reasonable plus return of capital.

The creative investor, or mining promoter, using the term in its best sense, is entitled to a larger return, but to state its exact terms is difficult. it would not seem unreasonable that he should receive double the amount of stock for his first purely speculative investment in actual cash, or assumed, obligation, but after the financing has been done it would appear to me he should only look for the same returns as the other investors. For example, suppose the promoter purchases a property for $100 000 and pays over $10 000 cash to ensure completion of sale, and it possibly costs him for engineers fees and other expenses $10 000 more; say it then requires $90 000 more for the development of the property, it would then seem entirely legitimate that he should receive at least twice his cash investment of $20 000, or $40 000 in stock in the property financed on the basis of $200 000.

MR. ROBERT LINTON:* The few comments I shall make on the subject of "Mine Valuation", which Mr. Finlay has presented to us in such an interesting and instructive manner, will apply chiefly to Western metal mines, whose valuation involves considerably more difficulty than the coal and iron mines of the East, and necessitates the consideration of elements of both value and risk that enter in to their development and operation in a widely different degree than is the case with the latter.

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For purposes of valuation mining properties are most conveniently classified into three groups, viz:

First: Prospects.

Second: Mining properties with ore bodies partially proven up.

Third: Mining properties with ore bodies entirely proven up.

Prospects. This group is the most speculative of the three, but the degree in which the properties included in it are to be considered speculative varies widely, depending on the character of mineral occurrence. In this group belong coal properties in which no diamond drilling or other exploration work has been done, but which are purchased simply on an acreage basis and the knowledge that the property is underlain with a certain seam or seams of coal. In the Pittsburgh and other similar districts, the fact that a coal property is not drilled does not usually introduce a highly speculative element. The seams are regular, practically unfaulted and of uniformly good grade. The variation in price per acre that such coal property brings is more affected by its location with reference to railroad facilities, going mines and known good coal, than by the fact that it is or is not diamond drilled. In the case of fields in entirely new districts, diamond drilling is absolutely essential to determine the thickness and grade of the coal, and in mountain districts, where the sedimentaries have been much broken and intruded, thorough exploration is necessary, as the seams may be so badly faulted as to make economical mining impossible, or the pressure incident to the eruptive action may have brought about a crushing of the coal in place.

Undeveloped iron ore properties, disseminated porphyry copper deposits, and large low-grade gold properties are little or no more speculative than the average undeveloped coal property. They require a considerable amount of money expended on them to prove up their value, but after this work is done, it becomes a comparatively simple matter of calculation to estimate the cost of equipment, operation and the total profit that will be derived from the ore body as developed.

Much more highly speculative are the high-grade metal

deposits which are habitually smaller, more scattered and more capricious in occurrence. In the development of this kind of prospects luck undoubtedly plays an important role. I have watched the development of such a property, which the owners bought for a small sum, started work and almost immediately opened a high-grade ore shoot from which they paid themselves back the purchase price of the property and all development expenses, continuing work until they had opened up an ore shoot of over half a million dollars in value. On the other hand I have watched the development of a great many other similar prospects where the high-grade ore shoot was hoped for but never found.

Mining Properties With Ore Bodies Partially Proven Up. This group applies especially to the class of metal mines which are characteristic of our Western states. These mines lie for the most part in fissure veins or in irregular lenses of ore formed by replacement of country rock. The Butte mines and the Bisbee mines are representative of these two classes respectively. The ore bearing formation ordinarily lies at a steep angle with the horizontal and frequently extends to great depths.

Now in developing such ore bodies, it is unnecessary to extend development work beyond the point where the outlay for milling reduction and other equipment can be repaid from the ore that is known to be available for extraction. It is where the property reaches this stage of development that it ceases to be a prospect and becomes a mine. Production may now begin, but development of the ore bodies must still go on keeping in advance of the extraction of the ore, as long as the ore lasts. And until the measure of an ore shoot is taken, horizontally and vertically, it can only be said to be partially proven up.

Mining Properties With Ore Bodies Entirely Proven Up. This group comprises mines where a definite tonnage of ore has been developed, but in which the limits of the ore bodies have evidently been reached; or to put it in another way, it comprises mines that are evidently approaching exhaustion of the ore bodies in which they lie. This group also includes

prospects on which sufficient work has been done to demonstrate that payable ore does not occur, or occurs in too small a tonnage to justify the installation of equipment to recover it. Coal properties that have been opened up and developed by diamond drilling and otherwise to the point of affording an accurate calculation of the tonnage available properly belong to this group.

These three classes of mining properties are characterized by varying elements of value and risk, which must be fully taken into account in arriving at an estimate of what they are worth.

Valuation of mines of the third class is comparatively simple. In the case of the developed prospect that has opened up no payable ore the value is nil. In the case of the mine that has a definite tonnage available it is a case of multiplying the number of tons by the net profit per ton, being careful not to overlook possible increase in cost due to mining at greater depths and decreased rate of production as the end of operations approaches, and not to estimate the selling price of the product at a figure higher than can be considered a reasonably certain average for the term of years the mine has to run. Rarely can any material liquidation value be attached to equipment or lands, as in nearly every case their value ceases when there is no more ore to mine. The purchaser of such a mine is justified in paying for it a sum that will be returned to him out of the operating profits by the time the mine is worked out, together with a reasonable profit. As the speculative element is eliminated, a valuation that will yield a very large profit is not justifiable.

Exactly the opposite condition prevails in the first group. Here, speaking of metal mines, the property has a supposed or potential value. The man who purchases and develops it takes a very considerable risk, and if he buys the property outright, is justified in paying only a small sum for it. In most cases these undeveloped prospects are held by persons who have located them, but have not the means to develop them. The most equitable manner in which to arrive at a fair valuation to both buyer and seller is for the latter to give an

option, or bond, to the intending purchaser, giving him sufficient time to prosecute the necessary exploration work to prove up the property. In other words, I would consider the value of a prospect to be ordinarily the cost of doing a certain amount of development work on it. If this work results favorably the value is greatly increased, the purchaser takes over the property and makes a profit on his purchase price plus cost of development work, and the seller receives a return considerably larger than he could have obtained from the sale of the undeveloped prospect. If the results of the development work are negative, the proposed purchaser loses only what he has expended for development work, and the owner, losing nothing, or practically nothing, knows what the value of his ground is.

In considering mining properties of the second group, the conditions combine those which prevail in the first and third. There is a definite tonnage of ore that can be measured and sampled, and there is an unknown tonnage of undeveloped ore. Such properties have, however, the advantage over the unexplored prospect, in that the development work that has resulted in opening up a material tonnage of ore affords definite information in regard to the manner of ore occurrence, and is a much more accurate guide in forming an opinion as to the future of the property than mere surface indications can give. The value of properties of this class is therefore determined by calculating the profit that will be derived from ore that can be measured and adding to this such an amount as, in the opinion of the purchaser, or owner, appears to be justified. Needless to say this amount usually varies widely as estimated by the owner and the prospective purchaser.

As the value of a mine depends upon the net profits that will be earned during its life, its valuation is primarily a matter of calculating, or estimating, the average grade of the ore, percentage of values that can be recovered, cost of production, and cost of development and equipment, bearing in mind that all charges against the property must be liquidated out of the earnings. It must also be borne in mind that conditions not directly incident to the property itself may materially affect its value. For instance the building of a rail-

road, a smelter or a commercial hydro-electric plant may make profitable the operation of a mine that otherwise would be idle, and providing these facilities adds a definite value to the mine. The development of new metallurgical processes, improved mining methods, or more efficient machinery may also make it possible to operate at a profit a mine that has been considered of no value, or may add materially to the tonnage of ore that a mine will yield. The development of the cyanide process brought numerous gold and silver mines into activity that had been considered too low grade to work, and at the present time the development of flotation and leaching processes give promise of having an equally far reaching effect on the copper and zinc industry. Also changes in the price of metals must not be lost sight of, as the price at which the mine's output can be sold is of the most vital importance. Many millions of dollars in revenue were produced by silver mines that operated and made large earnings when the government price for silver was $1.2929 per ounce, when the same mines could not make expenses under present prices.

In what I have said above I have confined myself to discussing the elements of real value that enter into a mining property. Other items, such as the past history of a mine, or the district in which it is located, or the existence of profitable mines adjacent to the property in the same formation, properly have a bearing on the valuation of a mining property, but these items must be considered with careful scrutiny as they are the favorite arguments of the unscrupulous promoter.

The valuation placed on mines which is expressed by stock exchange quotations on shares of mining companies is frequently quite accurate. Such as are regularly listed on the New York or Boston stock exchanges, and which issue comprehensive reports of the operations of the companies represented, offer to the investor securities which, while yielding a higher average return than railroad or industrial stocks, involve no materially greater risk. Such stocks always sell lower as the properties represented approach real or apparent exhaustion. The mining share market is subject to the same fluctuations due to financial conditions, and manipulation, that

other shares are subject to and, in addition, prices are affected by the rise and fall in prices of metals. As a rule, however, I believe that the investor who buys mining stocks in times of depression, or when metals are selling low, i. e., buys at such times the standard dividend payers that are listed on the New York and Boston exchanges, runs little or no greater risk than in investing in any other line of securities and makes a higher profit on the investment. I would not be understood as taking the position that mining stocks listed on the above exchanges are the only good mining stocks on the market, but there is no doubt that the strict rules governing listing are a great safeguard to the investor, and they represent the kind of mining securities that are safest for the casual investor.

MR. S. A. TAYLOR:* The paper of the evening, I assume from the outline, will apply largely to metal mines and yet I think the subject as applied to coal mines is of equal importance, and in this immediate locality is of much more general interest not alone on account of the financial investment but on account of the general business interest which is so necessary in a coal mining district. Therefore what I will say, will be confined to "Coal Mine Valuation."

In valuing coal properties, it is necessary to differentiate between the raw or undeveloped property, and the equipped. or going mine.

The first is somewhat analogous to the prospect for a metalliferous mine in that as nearly as possible must be determined the occurrences of the coal seams, their regularity through the area under consideration and the thickness of the seams, in order to ascertain the available tonnage, the character of the coal, the cost of land equipment and mining, the locality with reference to transportation lines, and last, but by no means the least, the markets, whether the coal can be mined and marketed at a profit, for notwithstanding that all of the above characteristics may be found to be favorable, if the market conditions do not indicate a profitable mining proposition, the proposition has little financial value.

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The second phase of the subject above mentioned arises after the matters pertaining to the first phase have been ascertained to be favorable and the mine opened up and equipped for producing coal, or as is frequently the case, has been in operation for some time, when it is found that more money is needed for a successful operation and refinancing becomes necessary. When this time comes, it is very important to the investor to know that the money which he will invest is secure both as to principal and interest, whether the principal shall be invested as preferred stock or bonds, and that the total of such securities will not exceed an amount that the mine would readily sell for, in case it became necessary to realize on the securities. In addition to the above condition, in the case of a bond issue, there should always be provided a sinking fund of such an amount as will readily liquidate the amount of the bonds and still leave a safe margin of security in the property; after the amount necessary to liquidate the preferred claims, there should still remain sufficient margin to pay the holders of the common stock a good, fair return for the risk taken and the time put into the enterprise. From the above statement it will be at once apparent that to have a good mining property, two things must obtain. First: That the property will pay back all the money necessary to be invested to make a successful mine, with a fair interest thereon. Second: That over and above the first requirement there shall exist a margin sufficient to warrant the party, or parties, who are competent, to devote their time to the enterprise, and if both these conditions are not found to exist with some degree of surety, the proposition had best remain undeveloped for the time being at least.

In determining the above facts, each engineer follows a slightly different method of procedure, but in the end the result is much the same if the examination has been thorough. To this end and in order to guard against the oversight of conditions and equipment, it is well to have a schedule, or a skeleton, of a report to fill in which when complete will give all the facts necessary to make up an estimate of the value of the property.

The outline which I follow is as follows:

(A) Subdivision of lands—Determine.

(A-1) Location, exactly from maps, surveys, or any accurate method at hand.

(A-2) Occurrence of coal seams.

Geologically, persistency, thickness of seam, chemical and physical properties of the coal, whether good for coke, gas production, steam, splint, domestic, or metallurgical purposes. To do this it will be necessary to open up the seams of coal, if above drainage, at various points on the property; and if shaft, diamond drill holes should be put down and cores taken out; this will enable the investigator to secure levels to determine the lines of strike or dip of the seams, to secure samples for the determination of chemical and physical properties. These samples should always include an equal amount of coal from bottom to top of the seam throwing out only such portions as would be easily excluded in the every day operation of the mine.

(A-3) Ascertain all available information relative to transportation facilities, both present and possible for use in the near future, as well also freight rates to the markets—and the markets themselves both as to character, quantity and desirability.

(A-4) If the property is virgin, then estimate and determine the cost of opening up and equipping a mine of such capacity as will be necessary to make it a profitable operation, or large enough to supply the market, if the market is limited.

(A-5) If the property is an operating property, then proceed to make a careful estimate of the value thereof as follows:

1. Determine value of land both surface and coal—owned or leased.

2. Determine value of all buildings placed upon property whether necessary or not (and make note) especially of those not necessary for the successful operation of the mine, and report on same.

3. Determine value of improvements such as mine openings, shafts, slopes, etc., tipples, railroad tracks, machinery, above ground or outside of mine.

4. Determine value of all improvements inside of mine, such as railroad tracks, mine cars, pumps, motors, etc., etc.

5. Determine value of all property used both inside and outside of the mine.

(A-6) Miscellaneous equipment such as office requirements and small accessories, which are a part of the operation.

(A-7) Summary: In which after proper values are given and allowed, the Engineer should state briefly, (if he has had a specific value or amount of valuation to be reached for the property), whether the property is a good investment for the proposed price, or just what value the property has, if his problem has been simply to ascertain the value. He should also state whether he considers the property sufficiently meritorious to warrant its development and any

other matters and things which his experience would dictate that he should call special attention toward in order to avoid losses, and make the investment a profitable one in case it is developed.

Mr. W. L. Affelder: I would like to ask Mr. Fohl where he got his figures of 500 tons per annum to the oven.

Mr. W. E. Fohl: That is partly derived from statistics of the United States Geological Survey carried over a term of twenty years. It is slightly larger than those statistics would show as the average of all the ovens in the Connellsville district and quite a little less than the standard 12½ ft. beehive oven will actually produce. It is an attempt to take into account the fluctuations in the market, that is, there are many years in which ovens can not be run full and this 500 ton figure I have used for a good many years as an attempt to take into account the fluctuations in the trade. I know ovens that are producing somewhere around 700 tons per year when they run full, but this is not calculated on full running at all times.

Mr. W. L. Affelder: The reason that I asked the question was that the standard beehive oven today will produce 720 tons per annum. And figuring as their full run the equivalent of only 215 days capacity per year looks to me as rather low figuring. If the tonnage had been figured at 720 it would have made the interest charge 41c instead of 59c per ton. I am inclined to believe that the figure of 215 days for a year's operation is a little low. Not that I intend to criticise Mr. Fohl's paper, because I think it is an unusually good one.

Mr. W. E. Fohl: I hope Mr. Affelder will take into account that those figures were obtained on a life of forty years, and there are many exigencies in the coke trade during forty years of life.

The Author: The several gentlemen who have contributed to the discussion have brought up several points that I think may be of general interest. While the taxation of mines is not necessarily a matter of valuation of mines except indirectly, yet I would like to say in regard to Mr. Rice's comments that I think he is right. The question put up to me in the Michigan case was not "What do you think would be a fair basis of

valuation or of taxation'', but ''What do you think these mines are worth?'' They wanted to value a mine just as they would value a house, put a value on it. I answered it this way: ''As far as I can make out this mine will last so long that if you want 5 percent on your money, if that is enough for it, its value would be about so and so.'' Personally I do not believe in taxing mining properties that way. I forget what they call it, ad valorem taxation, when it is based on a specific valuation. I think on the whole it would be better to tax mines on an income basis, particularly metal mines. While you can say certain things about the life of a mine, after all it is always a problem. In 999 cases out of 1000 the actual profitable life of a metal mine is really uncertain.

You may take this point of view, that even an unsuccessful enterprise may employ a good many people, and it may take a considerable investment, and it owes something to the state for the protection it receives for that property while they are using it. Nevertheless it seems to me that until a mine is absolutely profitable, until it is paying dividends, its property should be taxed on a very nominal basis, a small value put on its improvements while it is in use. But if a mine makes a great deal of money and becomes very profitable, then it seems to me that it is a fair thing that it should contribute more, it should contribute a portion of its earnings to the state. Several western states have a system of taxation which amounts to this; that the mine makes a statement of how much its gross receipts are and also what its gross expenditures are, all expenditures whether they are plant or anything else except perhaps the purchase of new property. Even if it spends a lot of money for improved equipment, that is all deducted just as the operating expense. From the excess of receipts over expenditures a certain percentage is deducted for taxation. That does not injure any one. In prosperous years when a mine makes more money it pays more taxes. In bad years when it does not make much money it does not pay so much in taxes. I think that is a fair way to get at it.

When it comes down to coal it does not seem as if that plan would be altogether satisfactory. If you only tax the profitable coal mines and do not tax the unprofitable ones I

think, in a good many cases, you would simply be taxing good management, taxing the good manager and not taxing the poor one, because coal lies usually so uniform, I suppose, and the products are of such uniform character that the question of profit is simply a question of management, either financial, or technical or both.

But when you come to another phase of the mining business, some of the points brought up by Mr. Linton strike me as worthy of comment. Let no one think that any kind of valuation whatever is a fixed thing. There is absolutely no such thing in the world as a fixed value for anything. I do not think gold has a fixed value. Sometimes it will buy more of the average commodity than at other times. It is an absolute certainty that any estimate you may make of value of any sort of property, real estate, mining properties, railroad stock or government bonds, is due to fluctuate according to the market. You get fluctuation from financial conditions. When people want money more than they want property they will sell the property for less. Then in the case of mines there is bound to be a fluctuation of value according to the condition of the property, the rate of development, whether the ore is being found in larger quantities than expected or not. That always influences people's opinions and is a fundamental thing which causes people to buy or sell and is bound to affect values.

I quite agree with Mr. Linton's division of mining properties into three classes, prospects, partially developed mines, and fully developed mines, although I must say that the fully developed mines are very scarce. I never saw one. I think you can make this generalization, that scanty ore deposits, the kind you find in prospects, are usually less valuable than they appear to be. There is generally less there than you might think from the general indications. But a good mine is almost invariably bigger than it appears. You might say there is a certain injustice in valuing a mine on more than there is in sight. The thing Mr. Rice brought up is a very good point, referring to taxation, in that taxation of a mine on its reserves is apt to discourage the development of ore bodies. But if there is anything in the world that is absolutely certain it is that a

metal mine if it is any good at all is worth more than it seems to be worth at any particular time. Personally I have very little use for the report of a mining engineer which is strictly confined to conventional terms and conventional measurements of ore in sight. Mining is not a manufacturing business in which you can determine accurately the factors you have to deal with. It is an art. It is an art in which personal judgment, ability, experience, play an enormous part. As I become older it seems to me that there is something about a mine that you can sort of feel. There is something about it that gives you a feeling that you are in the presence of a big mineralization, or sometimes you get the feeling that you are in the presence of a false alarm. And that instinctive understanding of the thing I think is the result of long experience. For my part I have an absolutely different view of the outlook of the average mine than I had ten years ago. I will give you the reasons why I have a different view. Ten or twelve years ago I was at the Portland mine in Cripple Creek, Col. Just before I left I asked the mining engineer, the surveyor there, to make an estimate of how much ore was in sight. That was what he was always talking about. He made an estimate and handed it in and it read something like this. There are 225 000 tons of crude ore, which would yield 90 000 tons of shipping ore. Well that was eleven years ago. I knew then that that mine would produce more, but I did not know how much more Eleven years ago the mine was producing at the rate of about 90 000 or 100 000 tons a year of shipping ore. There were 90 000 tons of ore in sight, remember. That mine has produced 90 000 tons of ore every year since. That is eleven years instead of one. And it has done it in the very area that was considered. There have been no further great developments. The mine has got deeper but to no great extent and the general area of exploration has increased very little indeed. At that time I think there was something like forty miles of workings in the mine.

Then there was another case, the Goldfield Consolidated. When I went there about four years ago I discovered that there was only about 1½ years of ore in sight, only about 400 000 tons measured in a mathematical way. Of course I knew there

would be more, but that was all there was in sight. But I was so convinced that it would last longer that I remember saying to the directors, "I think you are perfectly safe in figuring on a five year life in that property." While they could not expect that the mine would produce as much or as rich ore for five years, it would be running five years and the thing to do was to spend money while the mine was a bonanza to provide for a time when it would not be so easy to spend it. Well four years have gone and I notice today from the reports no decrease in tonnage. It is still profitable.

About four years ago I was asked to make a discussion of what could be expected of the Phelps-Dodge group of properties in Arizona. These are copper mines. I never saw them but I knew about them geologically and read descriptions and saw their records and knew what was in sight. Well the figure that it seemed to me it would be fair to value these mines at was a minimum life of five years. That is in the case of the Copper Queen where there was only three years ore in sight. A maximum life of ten years, figuring on the average price of copper, etc. I well remember I really did think from what I knew of those deposits that five years would be just about all there was in the Copper Queen, because there were other mines below in the dip. I do not know much about the present state of the mines, or the developments, but I notice that the output has been increasing every year since and I think the chances are very much in favor of the mine lasting a good deal more than five years and a good deal more than ten years.

There was a neighboring mine, the Calumet and Arizona that never did have very much ore in sight but it works right along. Where the mineralization is strong you are taking pretty big chances in saying that it will play out in a certain time. It generally does not.

I will give you another case absolutely to the point. Down in southeastern Missouri there are some great lead mines, much more important than one would suppose from the little that is said about them. It is the greatest lead producing district in the world, producing as much as the whole of Mexico, or Germany, or Australia. Yet it is all produced by four companies

that the public never hears about at all. Mining is done on a large scale and done very well. There is one mine down there that was started fifty years ago by the present company, the St. Joseph Lead Co. It was bought in in 1865. It had been worked on the surface for I don't know how many years before. In recent years the mine had been doing very badly. It was not very well managed for one thing, but it had produced 10 000 000 tons of ore and 400 000 tons of pig lead. That is a big output and the mine looked bigger than an ordinary mine that had produced that much because in that limestone the ore is all taken out of large chambers and the roof supported by pillars so that the whole space left by the 10 000 000 tons is still there. And that is some space. The record of the mine was that it had produced, at a guess, 80 lb. of lead to the ton in 1909, 70 lb. to the ton in 1910, 60 lb. in 1911, 50 lb. in 1912, and at the beginning of 1913 it had gone down to 45 lb. per ton. The cost of mining it had gone up until the mine was absolutely unprofitable. I remember saying to the man who was managing the mine that I did not believe it was worth while to pay much attention to it. I did not think that mine was any good. It had all the ear marks of a property that was on its last legs. You know people in the mining business depend a great deal on their optimism. A mine is usually worked for interminable years after it has ceased to pay. But the man who was running the mine said, "I have been through that mine and there are a good many things about it which make me believe that it has run down simply on account of bad management." Of course it was my business to go and look at the mine any way and examine it as carefully as I could. Frankly I thought the result would be that I would simply tell this man I disagreed with him. But several things convinced me that it was worth looking into. There were a lot of drill holes there, and so on. Finally I was convinced that the superintendent was right and it was a case of bad management and the thing could be brought up and made to pay profits after all. Now don't you realize that when a man takes that point of view and it is a serious report where they are going to spend money, he is taking serious responsibility. He has got to know what he is

talking about. The whole facts are that this young man who was running the mine made the thing come up right away. He was able to produce ore which was better each month. They were working three shafts, but they found so much ore it was only necessary to work one shaft, the original shaft that they started fifty years ago. The grade of the ore has gone up to 66 lb. to the ton, and I believe with proper metallurgical recovery it can be brought up to 80 lb. The cost of mining instead of being $1.15 has been reduced to 70c a ton. The fact is that the lead from that department is being produced for only 40 percent of the cost of a year ago. In the cost of mining alone $30 has been cut off of the price of the pig lead. And the drilling that has been done in the last year shows that it is not only a good mine but it has a long life ahead of it. When you come down to brass tacks about the mining business it is very unsafe to take information on the capital points at second hand. I do not think it is possible for the average man to keep track of a great many mines. If he is investing his money in them he can not watch all the mines in the country because they will get away from him, they will keep changing. And after all the main factor in the valuation of mines is how much ore can be depended upon, and in the final analysis the estimate of that is very largely a question of judgment and experience and not of concrete mathematical facts. I thank you for the attention you have given to this dry subject.

HOW THE ANCIENTS WOULD HAVE CONTROLLED THE MISSISSIPPI AND ITS TRIBUTARIES

By Sir William Willcocks*

(Published in the March, 1914, issue of the Proceedings of the Society, Vol. 30, No. 2.)

DISCUSSION

In the Proceedings of the Engineers' Society of Western Pennsylvania, Vol. 30, No. 2, March, 1914. the paper read by Sir William Willcocks on "How the Ancients would have Controlled the Mississippi and its Tributaries" contains certain references to the report of the Flood Commission of Pittsburgh, Penna.

The privilege of an engineer to discuss the work and opinions of his professional brethren is well known and this may even become a duty, if differing profoundly upon important public policies, affecting the safety, health and general welfare of the people. There is, however, a duty, fully as grave and customarily imposed, and that is that one shall completely inform himself before criticising the position and opinions of others. This is particularly true and the duty is all the more important when the critic occupies a world-wide position of renown and international standing in the profession.

As, in this address delivered at the invitation of the Engineers' Society, certain statements appear to attack the methods and findings of the engineering work of the Pittsburgh Flood Commission the members of the Engineering Committee believe it a duty to the profession, as well as to their associates on the Commission, to answer the sensational criticisms contained therein. The remarks of the author evidently were not based upon an accurate reading of the Flood Commission report. Had he carefully read and considered such report or obtained correct

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information in relation thereto, it is believed that his views upon the matter of flood control, as applied to our local rivers, would have been materially modified.

(1) The author undertakes to impress his readers that his opinions were based upon personal observations and at the same time to lodge a charge of incomplete investigation against those who have been responsible for the Flood Commission Report. For instance he says on page 128:

> "I never saw such bad looking stuff for reservoirs and I found that no one had bored down one foot to see."

As a matter of fact the author never visited a single reservoir site and fails to show the source of information, hearsay or otherwise, upon which he was relying for his extravagant statements. Upon the other hand, members of the Engineering Committee of the Pittsburgh Flood Commission visited the site of each proposed dam and satisfied themselves fully as to the presence of natural rock foundation.

(2) Again on page 128 the author says:

> "And your condition is such that if you had a high flood and a reservoir with 150 foot head on the hills above you and it happened to breach and come on top of the flood, all of the disasters you know of today would be but child's play. And if you had two in the same valley and the upper one burst and came down on the lower one, and the two came together, you might open the early chapters of Genesis and begin reading about Noah's flood to comfort you."

The purpose of the author's pleading is not clear. If he is adverse to dams of 150 feet or more in height because these are dangerous, we respectfully call attention to the fact that the highest dam proposed by the Commission is 143 feet in height and the average of the seventeen dams proposed is 93 feet. However, we further note that there are several dams in this country of more than 200 feet in height and the National Government is now engaged in the construction of a dam of 350 ft. in height on the Boise River in Idaho. Height simply requires adequate design and strength.

(3) Upon page 127 of the paper the following statement occurs:

> " This horizontal sandstone you have here and shale in alternating strata is considered the worst foundation for reservoirs of anything

in the world. More accidents to big reservoirs have happened on it than any other. If the strata are inclined at a steep angle and you build your dam on it, it rests on the hard particles and the weak strata are more or less ignored."

As the author very shrewdly abstains from giving definite information as to who holds these absurd opinions as to our local geological conditions and as we are addressing those who have knowledge of these matters, comment is unnecessary.

(4) Upon page 128 the author states:

"In your book you show that you spent money on many things, but not one penny to show what your foundations are and all the rest of it is worth nothing until you are sure of your foundation. You ought to spend some $10,000. for drills and take two of the nearest sites and expose the foundation and see if you can build a dam there. If you find real good foundation your difficulties will be at an end."

Engineers of ability and experience engaged upon a preliminary study and general design, judge by the surrounding out-cropping rock, which indicates geological conditions. Thus the feasibility of location is determined and customary allowance made in estimates of costs for depths of foundations. Later drillings will determine actual design and depth. Without undertaking to give detail answer to this criticism and show how the money was spent, all of which is stated in the report thus mentioned, the engineers of the Flood Commission, after personal inspection of the sites, considered that it was unnecessary to spend any money for borings for the purpose of their preliminary report. But it goes without saying that before actual sites would be determined and building begun such borings would of course be made by those responsible for the design and construction.

(5) Upon page 127 it is further stated:

"In a recent book which you have written on this reservoir question I see that the quantity of water you consider necessary to impound in these reservoirs seems to be in excess of what you need. In all the calculations it has been assumed that when the river rises, its discharge increases up to its maximum stage.***** As in all these estimates you have allowed for an increasing discharge and not reduced by half for the falling gauge, a much smaller quantity of water than you have assumed would I think suffice to shelter you from these hours of high flood which produce all the worry."

This appears to be a criticism of the use, by the Flood Commission Engineers in their report, of a greater factor of safety than the author thinks necessary. It may be stated that the hydraulic measurements, upon which the quantities were determined, were based upon the careful methods of the United States Geological Survey and of the Pennsylvania Water Supply Commission and many of the stations were operated in cooperation. Full and complete allowances were made in the rating curves, notwithstanding the above quoted comment, for the fact that river velocities are not the same upon rising and falling stages. This statement can be verified by reference to the rating diagrams in the report.

(6) The weakness of the author's paper and of the apparent criticisms of the Flood Commission's report are due to two facts: The opinions expressed in the report were based upon five years' study by engineers who possessed full knowledge of local circumstances and who therefore do know, whereas the remarks of the author emanated from a necessary cursory and hasty examination of the subject and conditions.

(7) The engineers of the Pittsburgh Flood Commission have the highest appreciation of the professional and ethical responsibility of opinions upon such a question as flood control and regret that so eminent an engineer should undertake to speak to the world upon such an important subject without fully informing himself as to the data from which he draws his conclusions.

GEO. S. DAVISON,	M. Am. Soc. C. E. Past Prest. Eng. Soc. West. Penna.
PAUL DIDIER,	M. Am. Soc. C. E.
GEORGE M. LEHMAN,	M. Am. Soc. C. E.
JULIAN KENNEDY,	Past Prest. Eng. Soc. West. Penna.
MORRIS KNOWLES,	M. Am. Soc. C. E.
E. K. MORSE,	M. Am. Soc. C. E. Past Prest. Eng. Soc. West. Penna.
EMIL SWENSSON,	M. Am. Soc. C. E. Past Prest. Eng. Soc. West. Penna.
W. G. WILKINS,	M. Am. Soc. C. E. Past Prest. Eng. Soc. West. Penna.

Members Engineering Committee,
Pittsburgh Flood Commission.

MR. THOS. P. ROBERTS*: We are accustomed to having America "done up" by English travelers after a week's tour of the land, but never before Sir William Willcocks has there appeared an engineer visitor from abroad, who, like him, spent several days in the Mississippi Valley, two days at Pittsburgh and then by rapid fire methods, proceeded to tell a large audience how much behind the ancient engineers of Egypt and Assyria the Americans are.

Sir William, in addition to his engineering accomplishments, which are, in certain directions, of a high order, is also a wit, and perhaps this wit is a weak point in his armour, for "cold facts", such as the vast majority of engineers are called upon to deal with, cannot well be made more palatable with any spice of wit or even Attic salt. But who can blame the distinguished traveler? He has learned that a mixed audience always enjoys humor, no matter what the size of the dose. He will entertain, even if he sometimes fails to instruct his auditors.

The traveler, while on the Mississippi, obtained a fairly good idea of the characteristics of the great river. and also some understanding of the nature of the problems engaging the attention of the U. S. Engineers. His remarks concerning the river are interesting, although not thoroughly consistent. It would have been better for him had he taken more time for study and conference with the engineers in charge of operations.

The same general remark applies to Sir William's observations of river conditions and problems in the Pittsburgh district. Overlooking his occasional mistakes, however, one cannot help but admire his quickness to grasp situations.

The present writer fully agrees with him as to the Pittsburgh Flood problem on the following points.

First: That, if reservoirs are to be built, they should be located as near the city as possible. Local storms (as was shown by the March 1907 flood) so far below many of the projected reservoirs, resulted in the highest flood ever recorded at Pittsburgh. While for such rain storms as visited Ohio and Indiana in 1913, averaging fully 8-inches precipitation over extended areas, would, if they had occurred in the water shed

*U. S. Engineer Office, Pittsburgh.

above Pittsburgh, have called for the accomplishment of the impossible. For nice well behaved storms over the "protected areas"—with not too much precipitation, something can be done with reservoirs.

Second: Sir William's advice not to count on flood reservoirs being made also available for power purposes, is sound and sensible.

Third: His advice to raise the streets and low lying districts in preference to relying upon flood storage reservoirs, is also sound, and is being put in practice by the City of Pittsburgh. In fact, on these points, Sir William appears to be fully in accord with the opinions of all the American river engineers who have given the flood problems along large rivers any considerable attention.

The present writer cannot agree with Sir William on certain other topics.

Thus he entertains the notion that the filling out of the banks of our rivers to the established U. S. Harbor lines has resulted in increase in height of floods with given volumes of discharge. Before lending his name to such an assumption, it would have been well had he first informed himself as to what was the old, or "natural", condition of our rivers. In connection with this he should have considered the mean bed slope of the streams, and the velocities imparted to the currents from various causes, aside from the bed slope. He should have thought of the fact also, that Pittsburgh is located between two rivers of given discharging capacity which unite to make one river with a discharging capacity equal to the two flood producers.

Thus, when our two rivers are simultaneously in flood stages, the Ohio also is "bank full" and consequently we have velocities passing Pittsburgh due to the mean river bed slopes which velocity is seldom over 5½ miles per hour. Such was the case during our very highest flood in March 1907.

Now as against this we may have floods from one arm of the Ohio, such as occurred on the Monongahela in 1888, which 50 miles up the river was 44 feet deep, yet, when it reached Pittsburgh, was reduced to about 23 feet, but with a velocity of 8 miles an hour. Its steep slope, commencing 20 miles above

the city, was due to the fact that the extra capacity of the Ohio to discharge it was able to take care of the water at but little over half (Ohio River) flood depth. At its 23 feet depth at Pittsburgh, the flood of 1888 from the Monongahela, was discharging fully as much as it discharged with 35 feet depth, during the 1907 flood.

Now for the "moral" disclosed by these facts. Sir William's attention was drawn to the case of the Monongahela river, which is narrowed at South 10th St. where three spans of the old bridge had been filled in, narrowing the river at said point to about 750 feet as compared with about 950 feet above and below 10th St. A very careful line of levels was carried along our rivers for miles after the March 1907 flood, noting numerous high water marks, etc. According to these observations, the contraction at 10th St. caused a local rise of only about 4 inches. Besides the contraction, it is proper to note there were also four or five piers of the old bridge helping to obstruct the free flow of the water. (There was some local deepening of the river section between the bridge piers). Such was the effect of the obstruction with a five mile per hour current.

Now had the current been 8-miles an hour, as it was in 1888, the effect of the obstruction at 10th Street would have been very much more, but, as has been stated, the flood being only 23 feet deep in 1888, its effect at the bridge was doubtless much more. The local fall may have been one and a half feet through a distance of about 200 feet. The current was very swift in 1888; breaking boats from their moorings, which were wrecked on bridge piers, so that this *low water flood* resulted in damages to boats, amounting to very much more financial loss than ever resulted from any of the high floods. The point is that velocities have very much to do with the effect of obstructions, and we do not have very great velocities when the Ohio is at high flood stage. Records of floods going back to the time of the first settlement at Pittsburgh by the French in 1754, and later, while the country was still a virgin forest, indicate no progressive increase in the height of floods.

In their original condition the Monongahela and Ohio rivers were noted for their caving banks. Fallen trees became responsible for snag piles, and these made sand bars, all resulting in

creating eddies and cross currents, more or less obstructive to the free discharge of water. The Monongahela is considerably deeper, as a whole, than in early times, which is manifest from the fact that the new locks, recently completed, have their miter sills arranged for 8-foot depth, whereas the old locks, with *precisely the same height of dams,* permitted only a low water draft of six feet.

Sir William was led into an error by observing loose stones along the water edge of our rivers, which he called "shingle", a correct word; but he erred in assuming that Pittsburgh was built over strata of loose stone, and hence, that water would flow freely beneath any walls built to restrain floods. Many others entertain the same opinion, but such a notion has no foundation in fact, except near the junction of the two rivers. Our river banks, as a whole, are absolutely impervious to river water, as is shown by the records of many wells driven over the bottom lands. The present writer, in 1879, working in the interest of the Pittsburgh Board of Health, (during a typhoid epidemic) had levels taken of the water in many wells on the South Side. With the exception of two of them very close to the river, the elevation of the water in all the other wells ranged from 5 to 15 feet, or more, above the elevation of the river. The direction of the subterranean flow and of the pressure of all springs, is from the hills towards the river. Everywhere the temperature and composition of well waters a little distance from the rivers in this vicinity, indicates no mixture with river water. Water backing up into cellars during floods comes from sewers, or passes along in the crescent shaped voids, usually left (by shrinkage of the earth) beneath tile pipes or brick conduits for want of care in tamping.

Dam No. 2 on the Ohio, closes the right hand chute of a very long island, composed of Sir William's "Shingle", yet, at times, the water in pool No. 2, may be fully ten feet higher than the water passing down the left chute, about 1000 feet distant. No water or "seeps" have been noticed as flowing beneath the island with such pressure. The facts are that if seeps developed, the first rise of muddy water would seal them hermetically. So, also, it has been noticed in building locks and dams on the rivers in this vicinity, that there is no flow

of water beneath the natural river bed. Springs, of course, burst through the compact sand and gravel at intervals in the bed of the rivers with pressures that even high flood depths cannot restrain, as is noted at filter cribs which happen to be located over river bed springs.

Referring to reservoir dam foundations, Sir William condemns with one blast the rocks of West Virginia and southwestern Pennsylvania. He says, "This horizontal sandstone you have here and shale in alternating strata is considered the worst foundation for reservoirs in the world. More accidents to big reservoirs have happened on it than on any other." etc. etc.

As the carboniferous, or shale series, west of the mountains extends to a depth of fully 2000 feet over much of the area, below the stream beds, it is evidently "all up" with big dams according to the dictum of the distinguished speaker. Perhaps Sir William is unaware of the fact that dolomite, and other hard rock strata, 25 to 100 feet thick occur in the series covering extensive areas, and crop out in the stream beds and hillsides at many points. Does he wish his readers to infer that such strata are not safe for dam foundations? The only reason which might be urged for their insecurity rests on the theory that water percolating through the rock will dissolve softer strata which may possibly lie beneath. This might be the case if air, or oxygen, had access with the water to certain thin veins containing sulphur. Hundreds of examples of water oozing through soft shale strata in the form of springs can be found in this district with no indication whatever of disintegration of the shale, and often this water may have several hundred feet of pressure behind it to force it through the shale. It is probable that the failures of big dams, to which Sir William refers, were sometimes due to faulty construction.

The importance of "cut off" toes to prevent leakage and upward pressure is, of course, very apparent. The present writer has had occasion to investigate the causes of failure of many dams in America and elsewhere, and is of the opinion that American engineers have given the subject of reservoir dam foundations more study based on test borings, etc., than the engineers of any other country. Having heretofore before the Society expressed certain opinions as to what should be done to

relieve the fears of the public in densely populated districts, resident below high dams, he need say but little more. Doubtless in time many tolerably high dams will be built above Pittsburgh for power purposes, and it behooves the authorities to require the companies to resort to every possible guard. There has been quite sufficient loss of life and damage to property in Western Pennsylvania to warrant only permits for such structures, which are safe against every contingency, even to the yielding of portions of the concrete work from causes, like expansion and contraction, which may ultimately bring about sudden failures. So far as strains, due to percolation of water in massive concrete work, careful studies have been made, and provision is being made in some cases for internal drainage of the concrete, by means of ducts and wells.

Sir William deserves much credit for emphasizing, as he does, the importance of planing for ample apron protection below high dams, especially in large streams. American experience with high dams has heretofore been confined, almost altogether, to comparatively small streams, with overfalls of but little moment weight. Even with dams of only 45 feet height on the Merrimac, the over fall in the course of time eroded at Holyoke what was considered solid, but really was shattered, or fissured, rock, to the depth of 25-feet, and undermined the dam to an alarming extent. Other examples, to the same effect, could be cited. Imagine a dam on the Merrimac, or other river of equal or greater flood discharge, 150 feet high, with a depth of 12 to 15 feet flowing over its crest, and think of its erosive force.

Some years ago the writer designed a dam for a tentative project of about 150 feet height at the Delaware Water Gap. Included in his estimate was a combination concrete and steel apron, extending to several hundred feet below the dam, there being much heavy ice besides water to dispose of. In addition it was part of the project to provide a rock fill dam a short distance above the massive concrete structure. Nothing short of such construction was to be thought of above such a populous district, which included the City of Philadelphia. It was costly, but it was disaster proof.

LIGHT HOUSE LENSES

By George A. Macbeth*

I had hoped to come before the Society without an apology, but it has been impossible to complete the fourth order "Flash lens" and also the fourth order "Fixed lens", and what is shown before you is only one-fourth section and one-sixth section of the two kinds of fourth order lenses—but they may serve as sufficient demonstration of the whole.

Also, it was impossible to complete in time, what I call the barrel lens, a "fourth order dioptric cylindric lens" because it is about as large as a barrel, being twenty-two inches in diameter; composed of the central bullseye ring and four rings of same diameter above and four below this middle bullseye, all of which must be accurately polished, as the design does not admit of any shifting in any direction, so if any inaccuracy occurs in any of the rings they are condemned and lost.

As this is the first time any such lenses made in the United States have been exhibited, it seems apropos and due the Engineers' Society to give a short retrospective and account of how such lenses were invented and used and the increase in their efficiency.

Not long ago there was published in the Geographical Magazine a well-illustrated article on light houses, but it dealt almost entirely on the construction of the towers and the fine engineering shown in these huge holders of the lights or lenses, like immense candle sticks as aids to navigation. Any one who has climbed the spiral stairs to get a sight of one of these glasses can see tonight half a dozen, sufficient to illustrate the system or plan of all.

The development of the lighting of coasts and marking harbors commenced about 1806, being called forth by the great

Presented at a monthly meeting of the Society and published in the April, 1914, Proceedings.

*President, Macbeth-Evans Glass Company, Pittsburgh.

destruction of vessels and loss of life in the previous year, involving some seventy vessels. Before this time, there were only half a dozen "beacons" on the coast of Scotland and in the life of Robert Stevenson, who was one of the great lighthouse builders and engineers, it is stated that the same condition existed on the coast of France. Previous to this time the entire coast signals for night consisted of "beacon" lights, that is, coal or wood fires on the tops of buildings, built for the purpose, but very uncertain and liable to mistakes—some vessels being lost by mistaking the fire of a lime kiln for the beacon light. The beacon at Firth of Forth was a very old one and had been kept up for over 180 years, being held as a private right and maintained by a tonnage on ships frequenting that harbor. Stevenson suggested the Bell Rock Lighthouse located about twelve miles from the coast of Scotland off the Firth of Forth; the building of this was a great engineering feat—very expensive and very slow, taking five years to complete, and in two years of this time only eleven days work could be done—a stormy coast, suggesting the one lighthouse to set the pace for the world.

Stevenson had no precedent but the example of an effort made at Liverpool a few years before of the use of parabolic mirrors, made of pieces of silvered glass, set in plaster, for reflector of light, and proceeded to try parabolic copper mirrors silver plated, each twenty-four inches in diameter by twelve inches deep—seven on two sides for white light and five on the other two sides for red, the plan being to alternate white and red light with a longer showing of white light than red as the lantern revolved. There was a loss of light by this method, but it was a very great improvement.

Sometime previous to this, there were some experiments made in conserving the sun's rays with lenses endeavoring to utilize the rays as a source of power.

Buffum in 1748 developed a new form of "burning" lens by grinding out the solid front of the glass so as to form "steps" or rings.

Condorcet built up this form composed of separate rings, each ring being a section of a sphere, but it was the ingenious Fresnel, in 1822, who adapted them for projection of light in

lighthouses. He was the first to introduce the cylindrical lens, designed to project the light in a horizontal plane in all directions on that plane. So in place of separate "reflectors", each of which lost a part of the light, as in the case of the Bell Rock Light composed of five red lights on two sides and seven white on the other two, Fresnel also introduced the one central source of light, but yet there remained much to do, as there was still much loss of light, some upwards above the lens, some

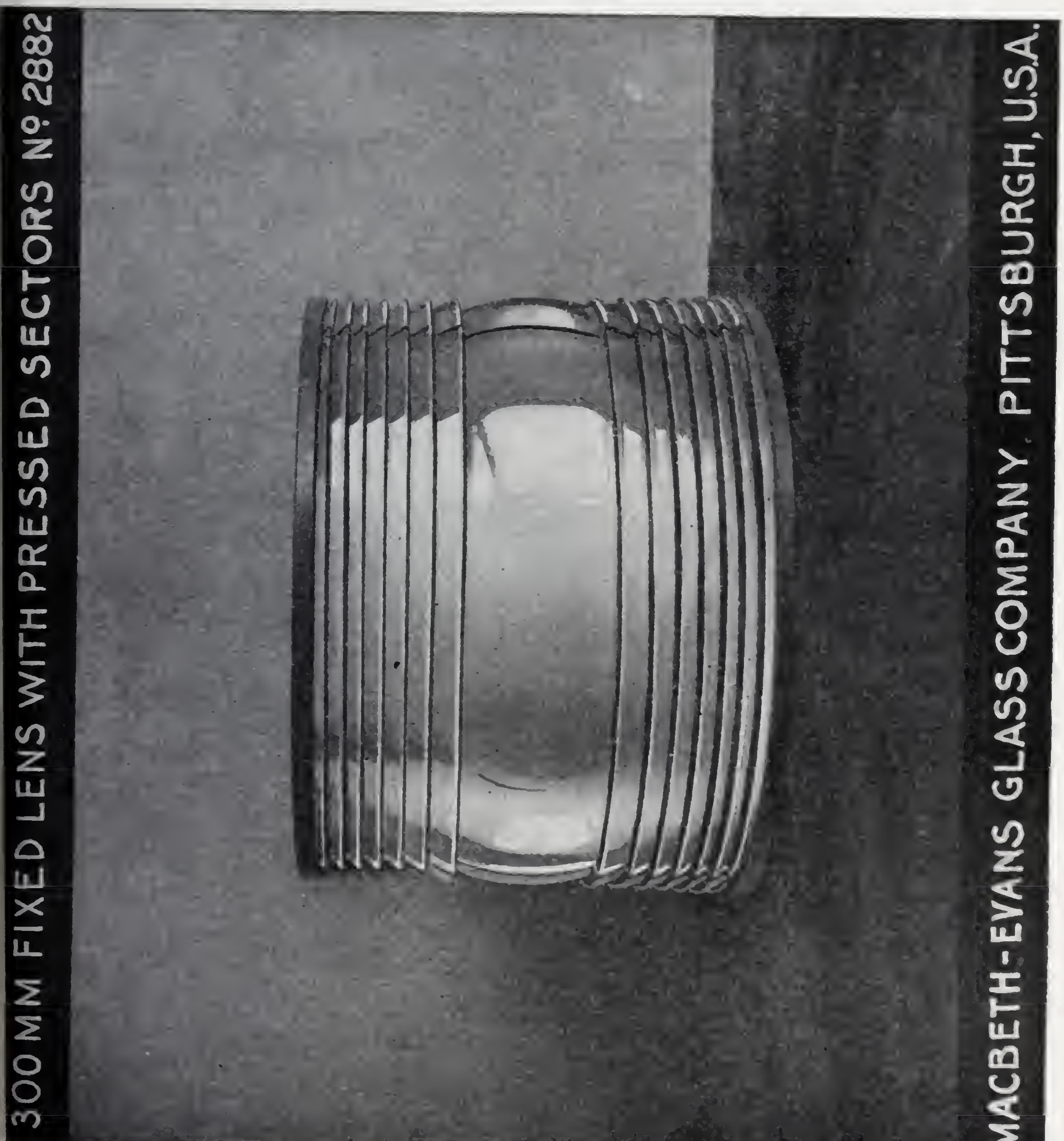

Fig. 1.

below, and it was thought to gather these stray beams by means of glass mirrors so as to *reflect* the light horizontally or in the same direction as those refracted by the lens. Mirrors, either metallic and silver plated, or glass silvered, were tried and abandoned, and Fresnel's genius brought into practical use the total reflecting prism or catadioptric portion of these lenses, thus increasing the efficiency very much, in gathering up the formerly lost or wasted rays of light and projecting in the

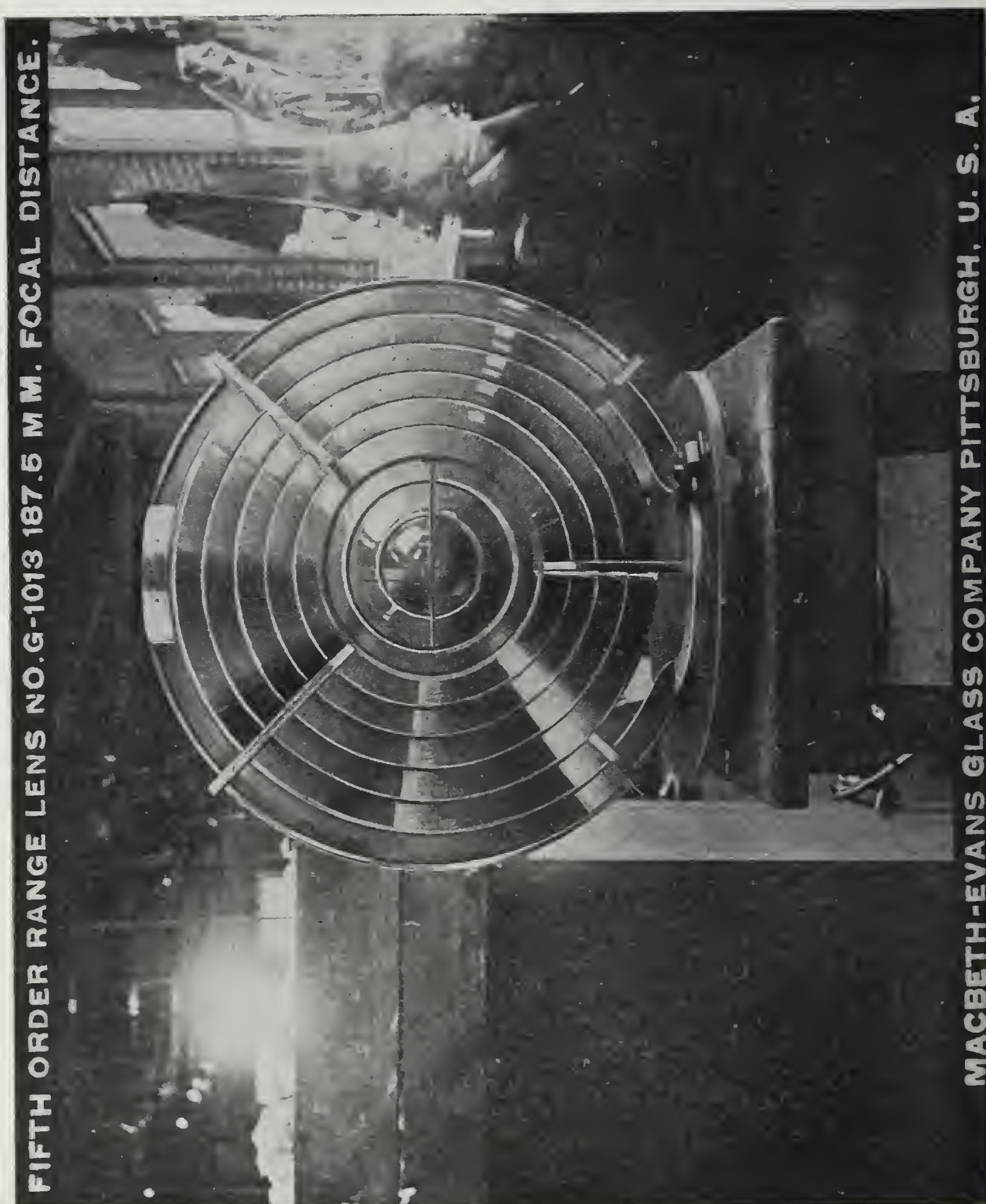

Fig. 2.

same direction as the dioptric or central bullseye part of the lens, increasing the angle, or in other words, the formerly lost rays were so utilized as to increase the efficiency of the central source of light some 40 or 50 percent. This finished the job.

This system is the one in vogue today and it is difficult to see how it can be improved for all the light, except that immediately above the flame or source of light, and all below, except that lost by the shadow of the holder of the source of light, is utilized.

It would take much more time than we have to describe the various forms devised since Fresnel's day. To project light in all varieties of directions, some like the "range light" for sending the rays in a round column, as it were, in one direction only. Others, a combination to project in two directions only, but the system is the same in all. In order to identify lights, Stevenson placed five red glasses over five reflectors on two sides of the lantern, and seven white lights on the other two sides—when this revolved the interval of red light was shorter than that of white. I cannot discover whether this was intended to get the benefit of the law of contrast, or simply a means of identification. Most likely, the latter, as no one makes mention of the law of contrast, nor of another important fact, namely, that a flash seems more brilliant to the human eye than a continuous light, 9/10 seconds being the time sufficient for maximum intensity.

The whole system of our lighthouse practice is to use both red and white flashes with various durations and intervals of dark and light; for instance, one light may have an interval of flash of two seconds duration, succeeded by three seconds of darkness. This flash is quite regular and sufficient for undoubted identification.

The Navesink light at Sandy Hook, 246 feet high, flashes one second and eclipses four and nine tenths seconds—sixty million candle power calculated—and is intended to show twenty-two miles in ordinary weather.

Fire Island light—167 feet high—flashes four seconds and eclipses 5.6 seconds. Calculated 160 000 candles. Rebuilt in 1858.

Montauk Point light—168 feet high—nineteen million

candles, flashes four seconds and eclipses nine and six-tenths seconds.

These lights are our most important ones.

Some good names have been connected with the subject of light source. Argand introduced the round hollow wick in

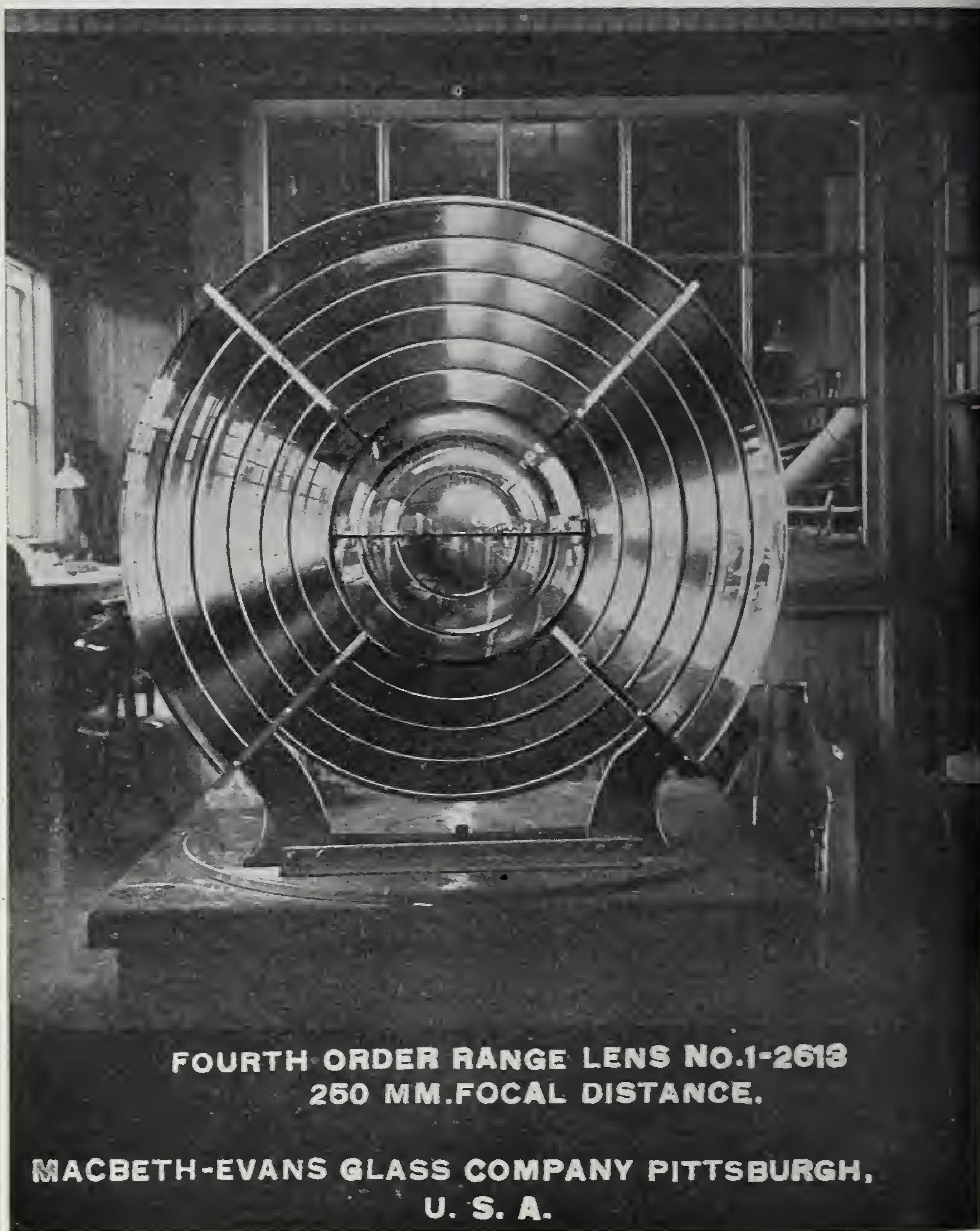

Fig. 3.

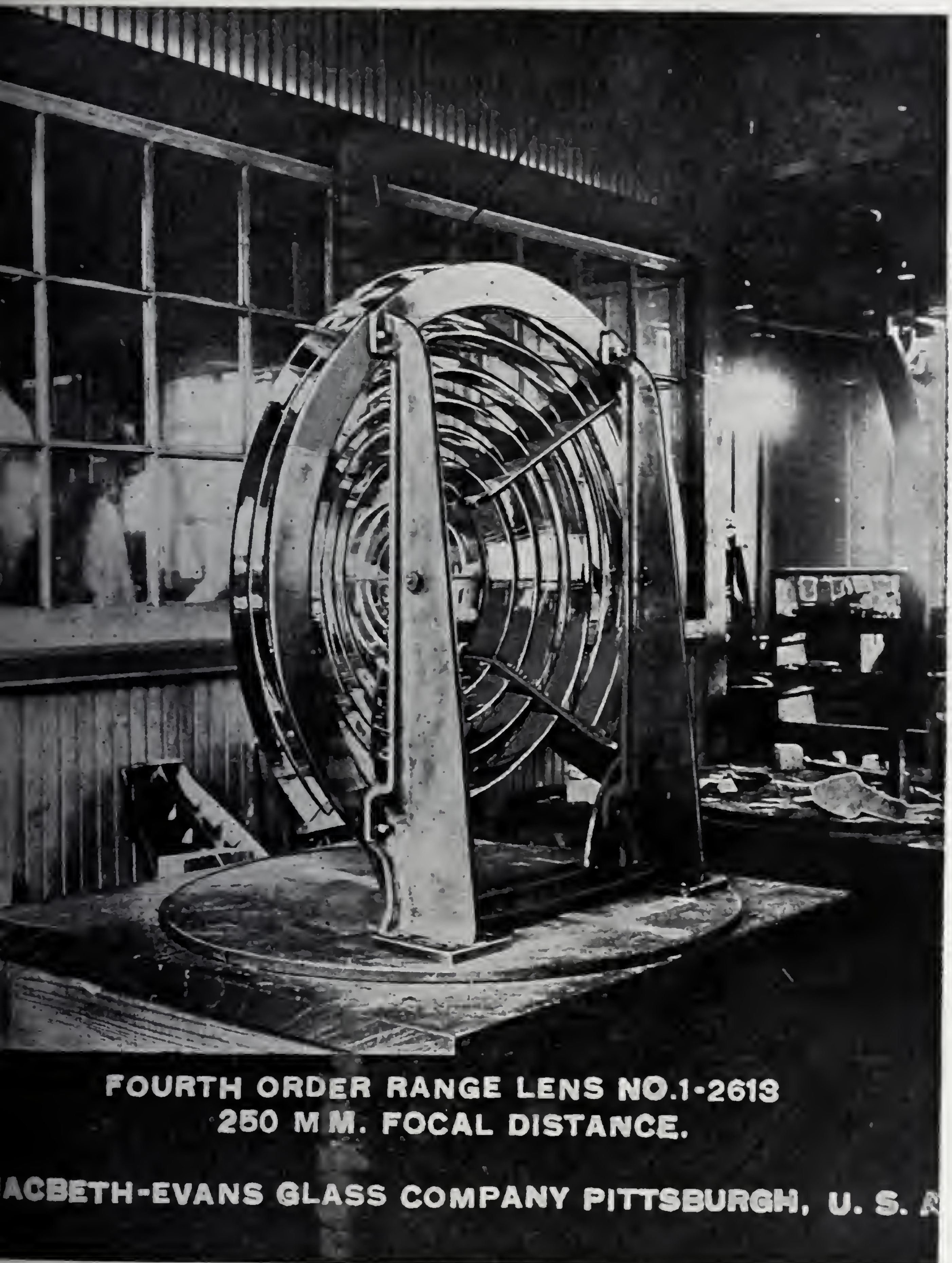

Fig. 4.

order to increase combustion in the middle of the flame, in addition to the outside hollow column of air. The next was the contracted neck chimney, to further force the air in contact with the top of the flame. Both were quite novel inventions in their day and have been ever since the guiding principle in all the lamps used for all purposes.

The glass to produce the best red has been a matter of rather slow development. From the first gold ruby glass was used and in order to secure against breakage was about one quarter inch thick. This was difficult to produce without a too dense color and consequent loss of light, also not being the best kind of red, as it contains blue, so the question has been to produce a red glass of proper thickness which would transmit the greatest amount of red light. This we have accomplished, producing an orange red and pronounced by the Department as "entirely" satisfactory. This is contrary to the practice of the railways, who seem to be willing to sacrifice transmission of light in order to use yellow signals.

It should be stated, however, that red, yellow or orange colored glass loses three-fourths of the intensity of colorless glass in transmission, green, five-sixths, blue, very much more and not used for such purposes. In other words, in order to project red rays as far as white, the illumination must be fourfold and for green six-fold that of white rays. This red we take to be the usual kind. That now approved transmits over forty percent.

I have mentioned the Bell Rock Lighthouse as it represented the best English practice and that country and France were all but simultaneous in adopting the best known and at about the same time. It was only in 1836 in Boston a lantern having fourteen lamps with reflectors was erected, and not until in 1859 was the Fresnel system adopted.

Serious dangers beset lighthouses, chief among them of course are storms. These lenses are protected by a lantern of glass, which is surrounded by a strong wire screen to protect from birds as the gulls and ducks when disturbed at night seem to act as if the lenses were holes in the sky and fly against the screen with such force as often to imbed themselves in the meshes. In 1912 in a lighthouse on the Pacific Coast, the lantern was destroyed by a storm, although it is 132 feet above high water. Officials assure us it was nothing else—incredible as it seems.

Another part of the subject may be of interest to you, as it illustrated a great stride in efficiency in all kinds of lighting. The light at Cape Hatteras, formerly a wick light with oil, rated

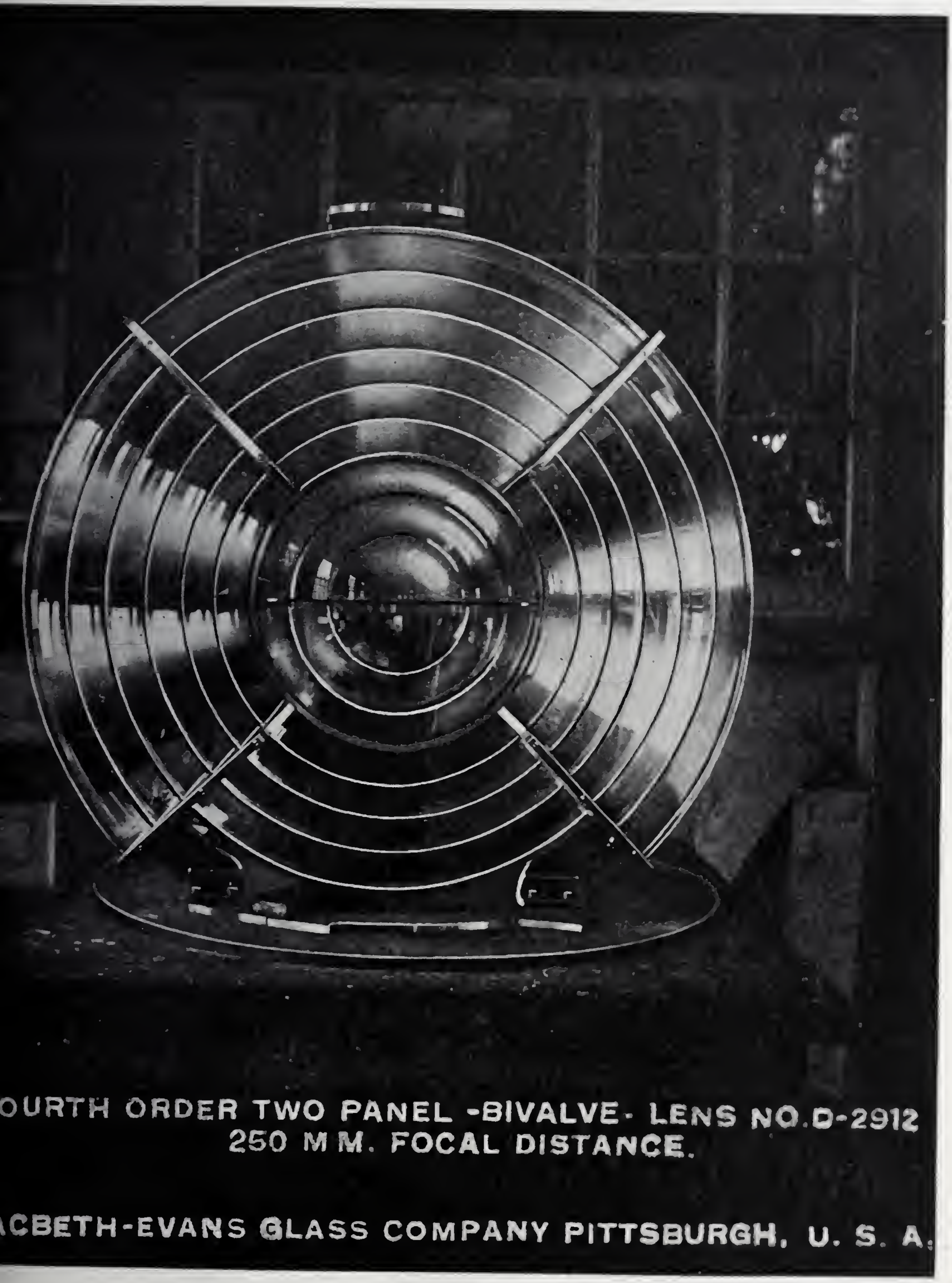
OURTH ORDER TWO PANEL -BIVALVE- LENS NO.D-2912
250 MM. FOCAL DISTANCE.
CBETH-EVANS GLASS COMPANY PITTSBURGH, U. S. A.

Fig. 5.

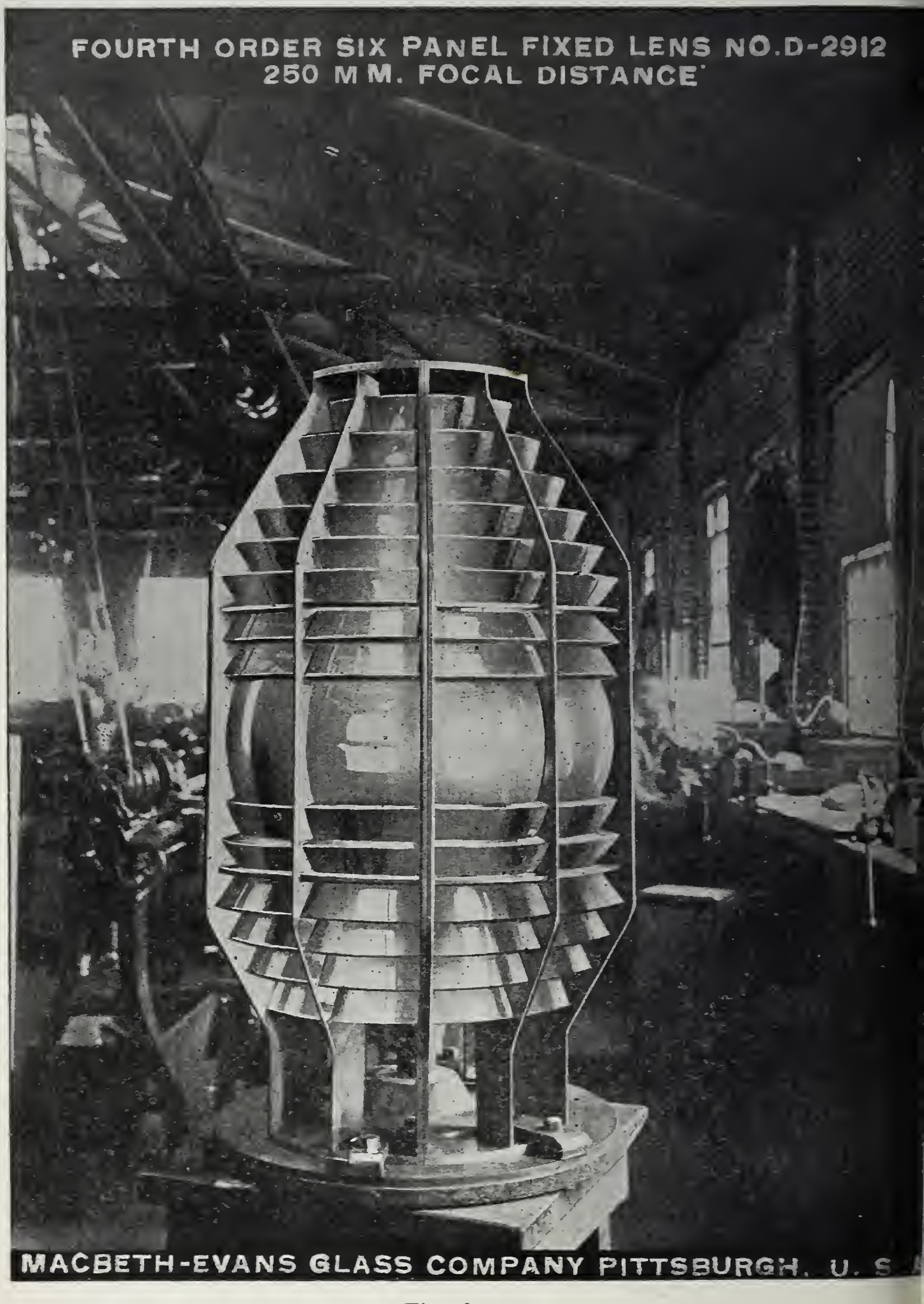
FOURTH ORDER SIX PANEL FIXED LENS NO.D-2912
250 MM. FOCAL DISTANCE
MACBETH-EVANS GLASS COMPANY PITTSBURGH. U. S

Fig. 6.

at 34 000 candles, was increased to 160 000 candles by the use of an oil vapor and mantle at two-fifths of former cost.

Our own Lighthouse Department certainly deserve great credit for the splendid efficiency and improvement in its forty-seven hundred lights, as indispensable aid to commerce on all our coasts. Every one of the lenses and mirrors go through most accurate tests and the requirements are most exacting.

The glasses before you are, commencing with the smallest

300 mm Buoy Light Lens (See Fig. 1)
187.5 mm Focal Length Dioptric Range Lens
187.5 mm Focal Length 5th Order Range Lens (See Fig. 2)
250 mm Focal Length 4th Order Range Lens (See Figs. 3 and 4)
250 mm Focal Length 4th Order Bivalve Lens (See Fig. 5)
Section of 4th order fixed Lens (See Fig. 6)
Section of 4th order flash lens (See Fig. 7)
Light Ship 5th order lens (See Fig. 8)
Also a glass used for red signals.

Besides the 18 inch Mangin mirror, other special mirrors and small lenses.

The 250 mm Range Lens is the same as those at each end of the Panama Canal.

The Fourth Order lenses have been improved in all respects and with the light sources used at this day are fit to replace the larger Third Order.

The various mirrors are much more than mere mirrors. The glass is special, polished front and back accurately, so that four, when placed in the brass frames, focus to a nicety and present a clean spherical surface, even at the joints. The back is electroplated with copper over the silver for protection and the copper protected again by coats of weather-proof material

The fifth order light ship lens was the first one attempted, and we recommend a glass of index of refraction of 1.55, gravity 2.95, in place of the former glasses of 1.52 index and 2.52 gravity, because of the fine polish and "permanence" of a glass we make of that character and which kept side by side with the former glass for a year or more remained bright and clean, while the glass usually used showed signs of change. It is harder to make, likely to have striae and bubbles—takes longer to polish, but when done, stays bright. Not being able to procure workmen with any experience in such work, the whole had to be invented—and the making involved a glass making problem, a mathematical problem, an optical problem and a

mechanical problem, to turn out an improvement in all respects. Prof. Hower has risen equal to the occasion in his accurate drawings and measures and design and Mr. Heupel in his accurate grinding and polishing and accurate make of the brasses and the intricate work of assembling, so I feel quite confident that with such team work we can make anything required and keep up the highest standard of excellence.

The lenses formerly made had quite a divergence from

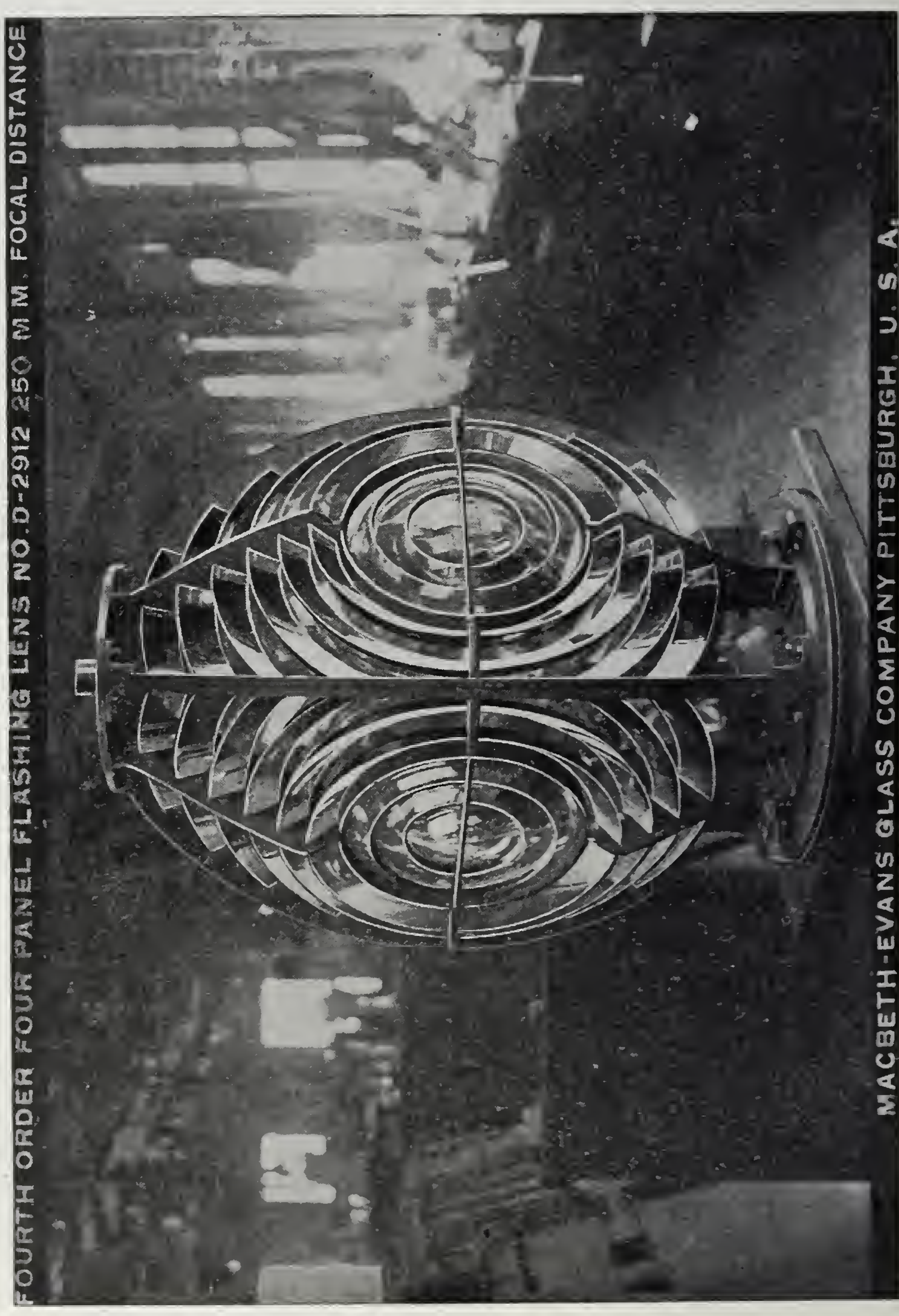

Fig. 7.

the horizontal, but are now required not over half a degree—the test we use being a chalk ball $\frac{3}{8}$ in. in diameter, placed in the focus. When viewed from a distance of forty feet each prism or reflecting prism must show the white streak of the ball clear across its face.

In commencing the manufacture of these glasses, it seemed like assuming a duty with unknown investment, as well as unknown loss or profit, but it also answered a challenge to an old glass center like Pittsburgh to produce high-grade articles and run the risk in the endeavor. The sequel proves that within the membership of our Society is the spirit and perseverance to produce anything wanted in this field of optical glasses.

This short account I have condensed from a variety of books and pamphlets—some telling one part, some another, and in going over the subject, not one article written omits the name of the man I am glad to hail as a genius of the first rank, Fresnel, the discoverer of polarized light, when quite a young man and lament his death at under forty years of age. We are getting the benefit of his work today.

It would take a large volume and illustrations to tell various adaptions and variety of arrangements, but after all it is Fresnel's work.

The Secretary of Commerce and Labor, under which Bureau the Lighthouse Department now operates, in his annual report of 1913, refers to the matter as follows:

"Until lately it has been necessary to procure all the cut glass lenses used in the Lighthouse Service from either France, England, or Germany, most of them coming from France. Recently the matter was taken up with an American firm of glass manufacturers with a view to ascertaining if a better lens could not be made in this country than abroad by using some modern manufacturing methods. The results to date have proven satisfactory. The lenses are superior to those purchased abroad and can be made for the same cost or less. The essential feature of the American method of manufacture is that the prisms are formed by machine instead of by hand. Every part is made to fit an accurate template or jig, so that they are true to size and parts of the same number are completely interchangeable. Improvements have been made in pressed glass lens lantern and buoy lantern lenses, and tests show them well adapted for many conditions of the service, at a decrease in expense."

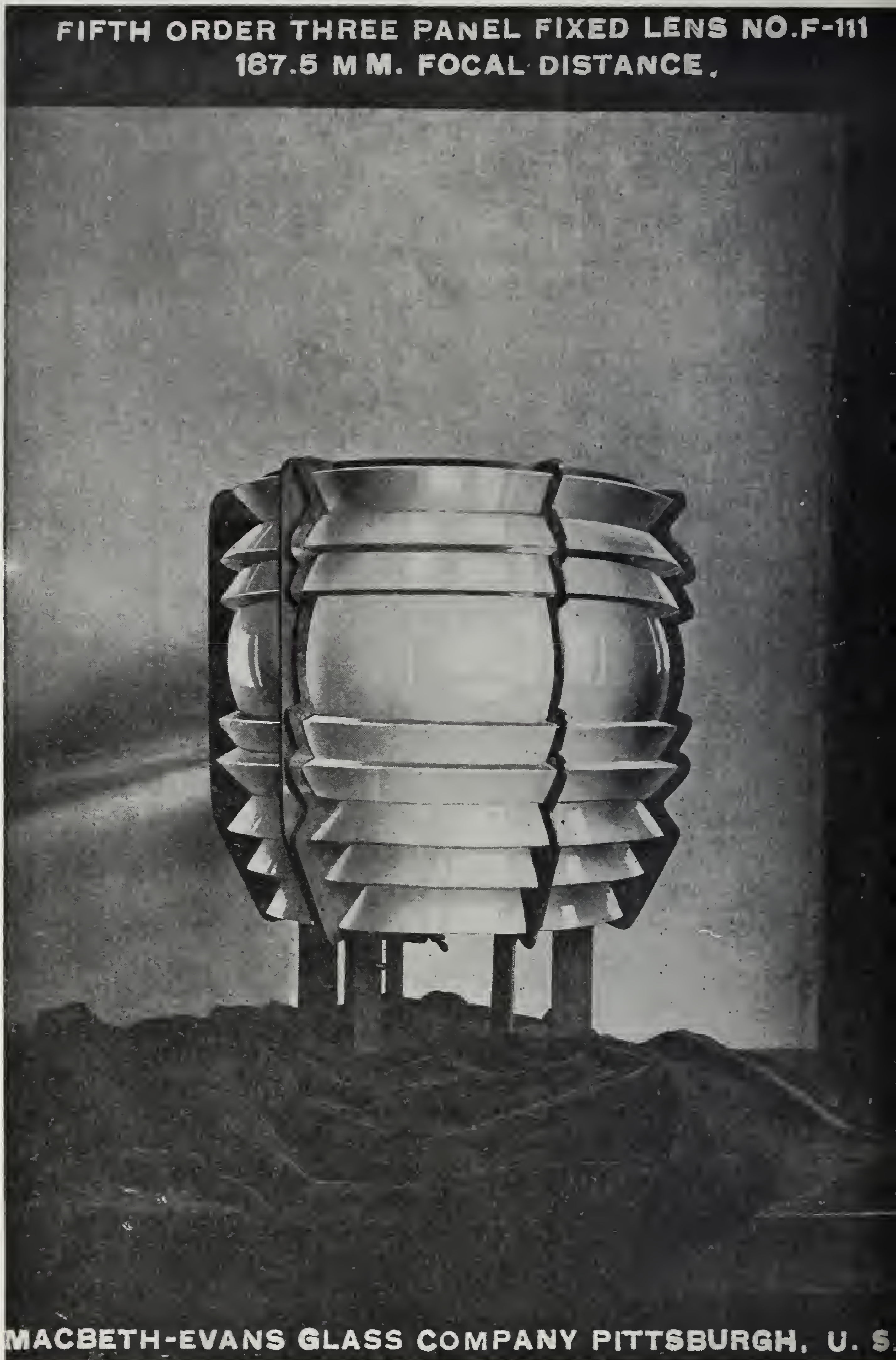
FIFTH ORDER THREE PANEL FIXED LENS NO.F-111
187.5 M M. FOCAL DISTANCE.
MACBETH-EVANS GLASS COMPANY PITTSBURGH, U. S.

Fig. 8.

The 300 mm lens was formerly made in rings separate and the inspection of several revealed the fact that all were not alike. We recommended an improvement by making them in 180 deg. sections, each section interchangeable and in one piece. These proved uniform and with increased efficiency over all former styles.

I have left for Prof. Hower things he can explain much better and more scientifically than I can, and thank you very much.

DISCUSSION.

Prof. Harry S. Hower*: Mr. Macbeth has asked me to add a few words with regard to the optical properties of the lenses he has described. Let us take the Fourth Order Range Lens as typical and consider the way in which it directs the light from the source, into a concentrated beam of great carrying power.

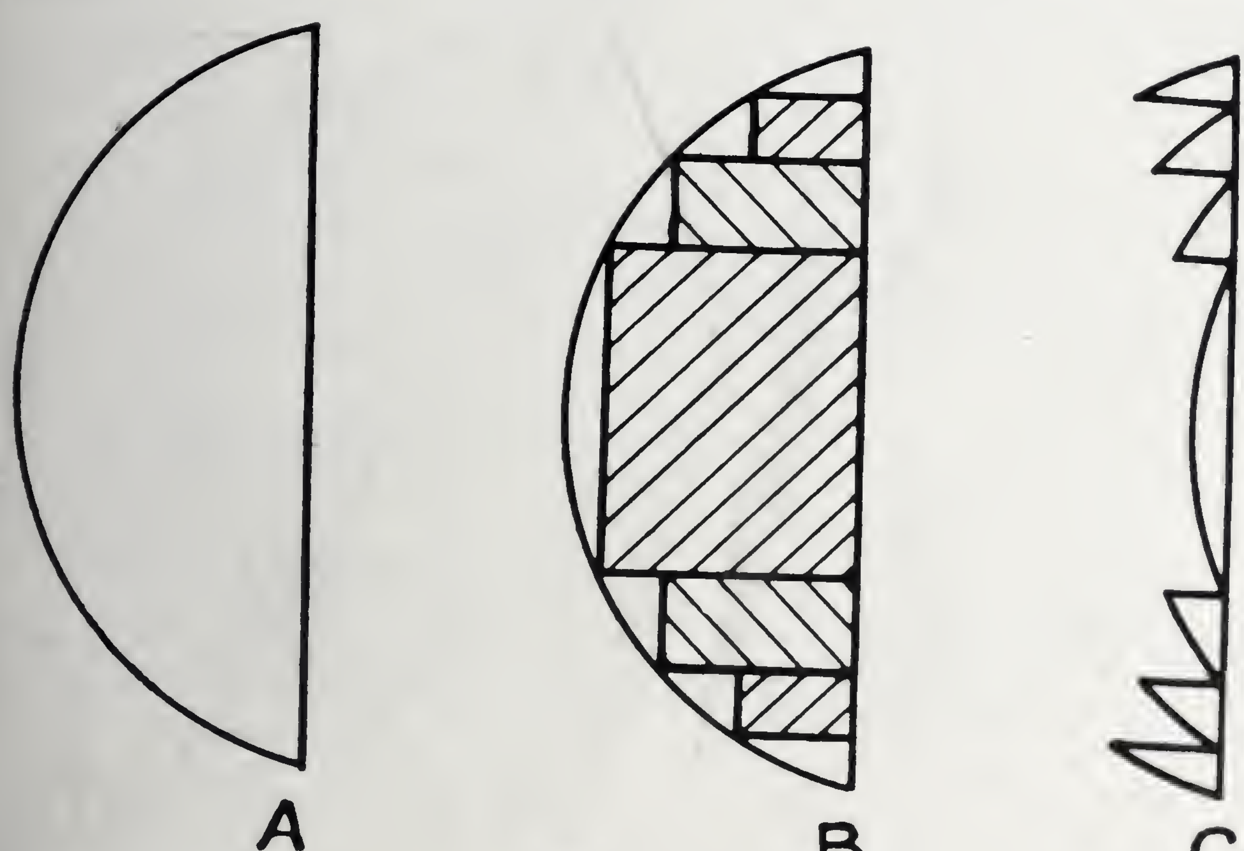

Fig. 9.

The central refracting portion of the lens (shown in Fig. 3) inside the brass ring was developed from a plano-convex lens, being first used to form a large burning glass and later applied by Fresnel to light-house lenses. A plano-convex lens of large diameter and short focus would be very thick and heavy.

*Professor of Physics, Carnegie Institute of Technology.

and would absorb considerable light from a beam passing through it. If this large lens (Fig. 9-A) were cut up in rings, part of the back ground off (Fig. 9-B), and the various rings telescoped together, we should have a lens (Fig. 9-C) of about the same focus, much lighter, and one which would produce less absorption in a beam of light passing through it.

The curved surface on a ring may be given a slightly different center from that which would be obtained in the above

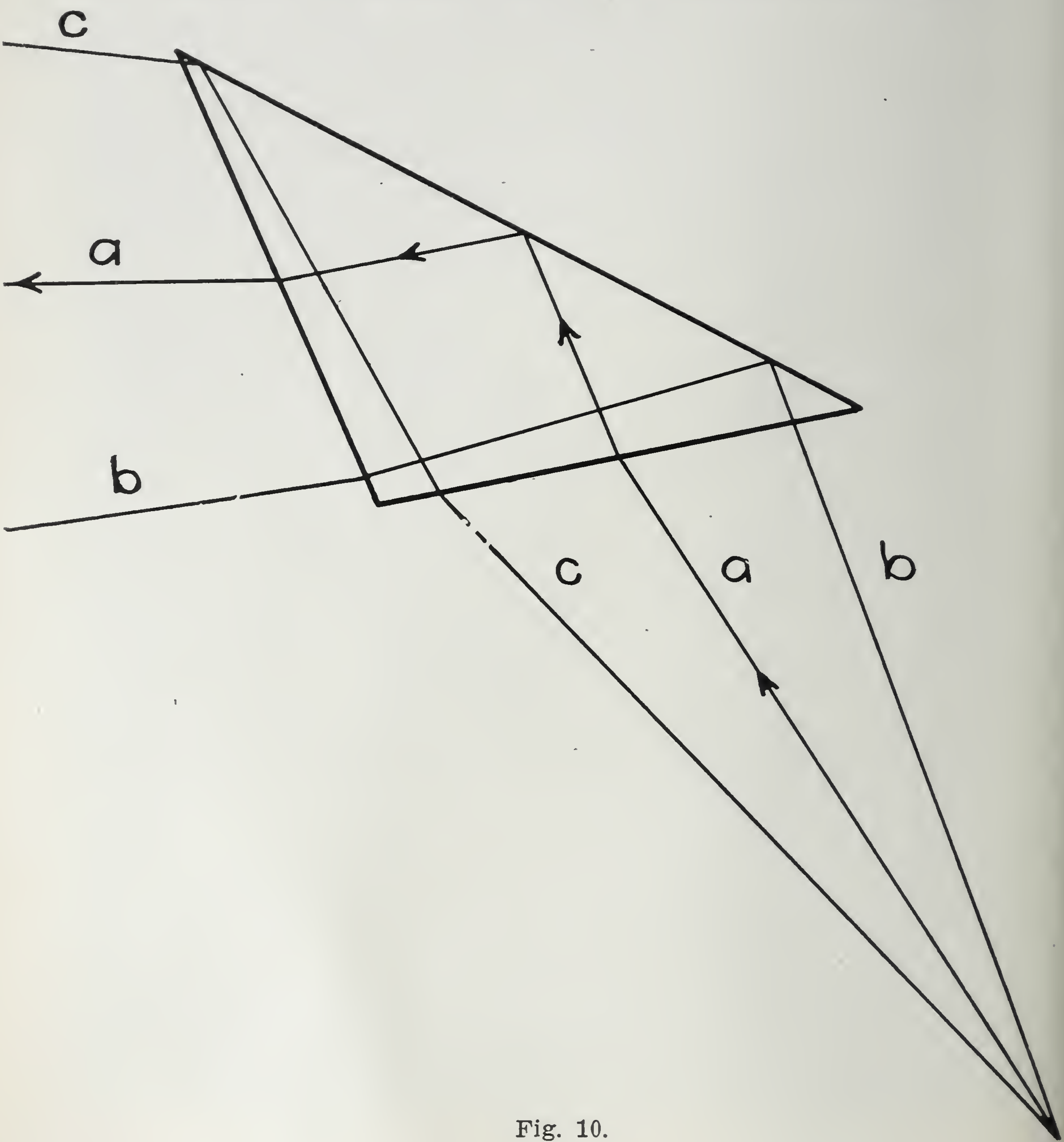

Fig. 10.

fashion and thus the lens made of rings, or the stepped lens, or the Fresnel lens as it is often called, may be made to have less spherical aberation than the plano-convex lens of excessive thickness would necessarily possess. This central portion of the range lens, which directs the light by refraction, is called the dioptric part of the lens—the rings being known as dioptric rings. It is made in the same form that it had a hundred years ago.

That portion of the range lens (Fig. 3) which lies outside the central brass ring operates by refraction and reflection, the rings being known as catadioptric rings. In the form of these rings there has been some improvement. In the earliest rings the principle of total reflection was utilized, but no lens action was secured, while in later years the section of the ring has shown one or more curved faces.

Figure 10 shows a prism with straight sides which will properly direct the ray *a*, but which will not correct the divergence of the rays *b* and *c*.

Fig. 11 shows the section used for the catadioptric prisms of our typical lens. The face *CB* is given such a curvature as to properly direct all the rays which enter it; that is, all the rays from the source after entering the prism through face *C B* proceed in directions parallel to *C A*.

The equation of the curve *C B* may be readily obtained as follows:

Let *OX*, parallel to *C A*, be the axis of polar coordinates. Then $P\ O\ X = \theta$ and $O\ P = r$ for *P*, any point on the curve *C P B*. If u = index of refraction of the glass then

$$u = \frac{\sin i}{\sin r_1}$$

where i and r_1 are the angles made by the incident ray *a* and the refracted ray with the normal $N\ N^1$. If *Q* is a neighboring point of the curve *C P B*, we have directly from the figure

$$\tan i = \frac{dr}{r\ d\ \theta} \text{ and } r_1 = i - \theta$$

$$\text{Since } u = \frac{\sin i}{\sin r_1} \text{ or } u \sin r_1 = \sin i$$

$$\text{Then } u \sin (i - \theta) = \sin i$$
$$u (\sin i \cos \theta - \cos i \sin \theta) = \sin i$$
$$(u \cos \theta - 1) \tan i = u \sin \theta$$
$$(u \cos \theta - 1) \frac{dr}{r\, d\, \theta} = u \sin \theta$$
$$\frac{dr}{r} = \left(\frac{u \sin \theta}{u \cos \theta - 1} \right) d\, \theta$$
$$c = \log r\ (u \cos \theta - 1)$$
$$\text{or } r\ (u \cos \theta - 1) = K$$

This will be recognized as the equation of an hyperbola.

The slope of the straight side $A\ B$ is determined by the equation

$$T = \frac{90 + S}{2}$$

where S is the angle which the mean ray striking the prism face $C\ B$ makes with the vertical axis. The angle U, which determines the direction of $A\ C$ is determined by the fact that the final direction of the ray is horizontal. From the figure we have

$i = T - U$ and $r = 90^0 - 2U$

Since

$$\frac{\sin i}{\sin r} = u \text{ or } \sin i = u \sin r,$$

then, $\sin\ (T - U) = u \cos 2\ U$

which may be solved for U.

The application of the three equations

$$T = \frac{90 + S}{2}$$

$$\sin\ (T - U) = u \cos 2\ U$$
$$r\ (U \cos \theta - 1) = K$$

gives the necessary data for a prism section which would perfectly direct the rays of light from a point source. To construct a glass ring with two conical surfaces and the third a hyperboloid of revolution, was more than any manufacturer had ever attempted. That the lenses Mr. Macbeth has described do represent the fulfillment of the above conditions is indicated by the fact that they have given as much as 50 percent more light than the old style lenses.

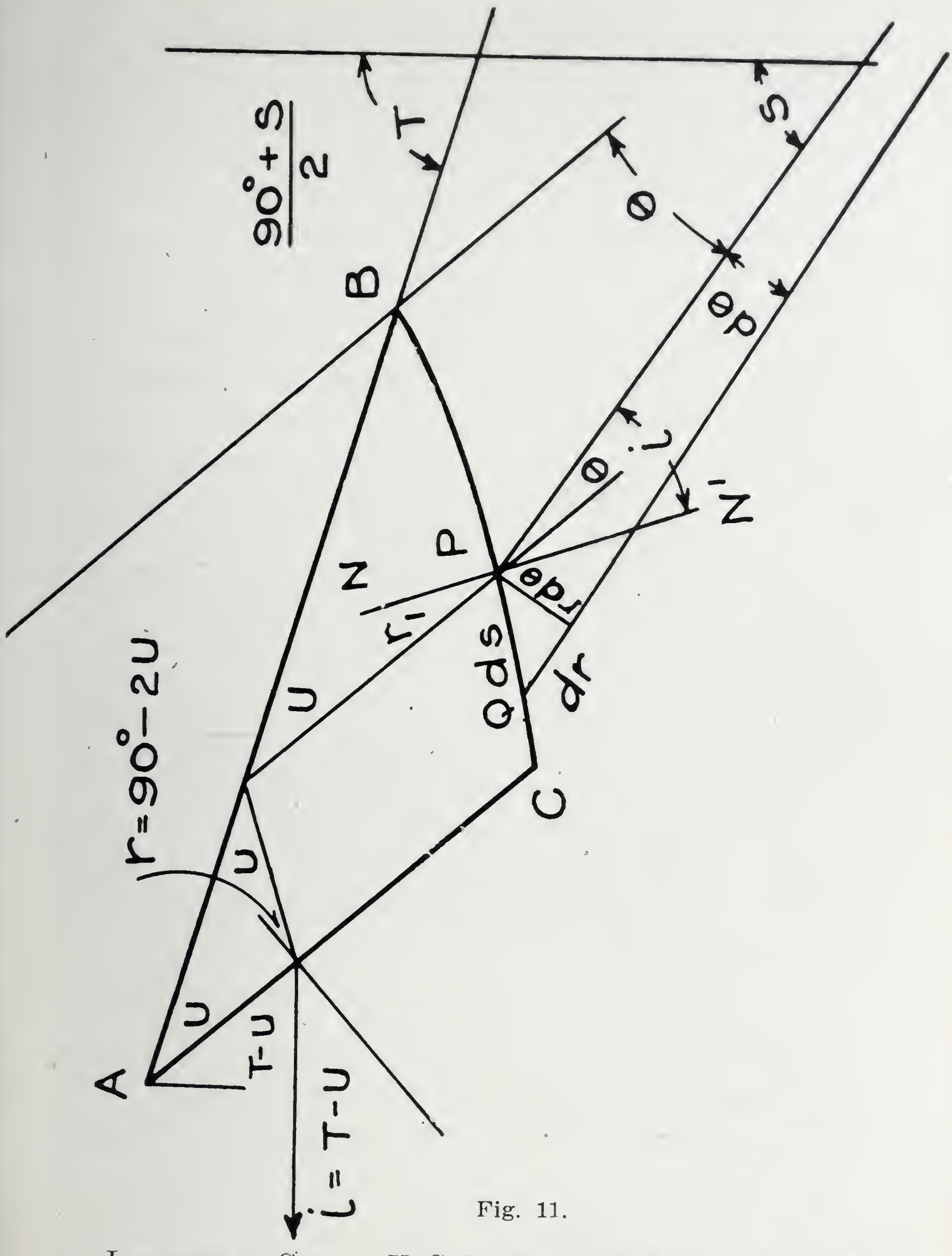

Fig. 11.

Lieutenant Cresap, U. S. Navy: I think I might explain to Mr. Macbeth that he has been speaking to a sailor. I am not an engineer but a sailor, and I have seen a great many of these lights, all the ones on the American Coast that he has talked about. I have had a great deal to do with searchlights and I think all the searchlight mirrors we use in the Navy

searchlights are made in Europe. I wondered if Mr. Macbeth has made any searchlight mirrors or has considered their manufacture. The Navy purchases each year about 40 searchlight mirrors of 24, 30 and 36″ diameters, about half being of the latter diameter, to make up for breakage, etc., and the addition of each battleship means the purchase of 12 or 15 mirrors of the 36″ diameter. We and the Navy Shipbuilders probably purchase each year, all told, about 75 or 80 mirrors. The Army must purchase mirrors also as they use searchlights extensively, although I have no idea as to the number they consume.

Mr. Chester B. Albree: It has been particularly interesting to me to-night to hear Mr. Macbeth talk and also to hear a talk on the theoretical end. Mr. Macbeth has shown thorough technical knowledge and the theoretical part has been well covered. I do think that it is a very great credit to the City of Pittsburgh—leaving Mr. Macbeth out of the question—that we have succeeded here in Pittsburgh in producing very much better work than they have ever produced abroad. I understand that heretofore, that is, until comparatively recently, our best lighthouse lenses all came from the other side of the ocean, but today by actual test the best lenses are produced right here in Pittsburgh, and I think we are especially honored tonight, regardless of whether he ever makes a cent of profit out of the venture or not, in having Mr. Macbeth with us.

PRINCIPLES AND DETAILS INVOLVED IN THE MOVING OF LARGE STRUCTURES

By George W. Nichols*

The question of moving heavy bodies has been one of great importance dating from the earliest records we have of man. The great skill acquired by the ancients in building their temples and other structures shows that they must have possessed considerable knowledge concerning the principles involved in this work. We are amazed at finding in many of these structures massive stones, weighing in many cases close to fifty tons, set in place hundreds of feet above the ground apparently with as much ease as were the smaller ones.

How they were able to transport such heavy stones miles from the quarries to the building site, and then to set them in place at such extreme heights are as unknown to us as were the individuals who directed their movements.

Many of these large stones have been discovered in the Pyramids of Cheops, which is the largest of the three pyramids erected at Gezeh. This pyramid covers an area of thirteen acres and was originally 482 feet high. It was built of limestone blocks and has many inner chambers, which are reached by sloping passages. It was built about the year 3700 B. C. by the Egyptian King Cheops.

This structure like most of the ancient buildings was built as a monument to its builder, the king; for which reason large blocks of stone were used and they were made as massive as possible, not only to better withstand the elements but also the destructive hands of their enemies and of following kings who

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*Engineer, John Eichlaey, Jr. Company, Pittsburgh.

would prefer to immortalize their names by destroying the earlier structures, in order that their works might appear greater.

We know that in the building of these ancient structures the labor problems of today did not concern the builders, for labor was in abundance, slaves being used. The element of time, rarely entered into their construction, consequently, when we try to arrive at their methods in transporting such massive stones and elevating and setting in place, we naturally infer that slaves were used in supplying the power required to do this work. As to the method of setting of stones at such heights, this may have been accomplished by a rocking motion on midway blocks a rather thicker block being inserted from time to time as the stone continued to be rocked. A much more probable method, however, considering the type of labor and the abundance, would be to build a gradual ascent to the required height, in the form of a road which could be extended back and built up as the building increased in height. After the completion of the building the road could be removed.

This was the method pursued in the erection of large stones in the construction of an old temple in India, in which case they are said to have built a road some five miles in length in order to provide the easy grade required, up which the heavy material was moved and finally set in place.

In considering the principles used at present in the moving and raising of heavy structures it will be well to describe briefly the material and equipment ordinarily used. To many this may seem quite elementary, but it may assist others in obtaining a clearer idea of the methods by which work of this nature is done.

The list would ordinarily include the following material: 6 by 8 blocks, screws, caps and collars, rollers, and roller plank, 6 by 8 runs, cross timbers or beams.

By blocking we mean the ordinary 6 by 8 blocks surfaced four sides which measure just 3-ft. 4-in. in length. This is a convenient size for handling and as the blocks are of one size, the blocking can be built up rapidly and easily kept level. Should the block pile show irregularity it can easily be made level by the use of shingles.

By screws we usually refer to the ordinary cast iron screw

having a diameter of nearly three inches and a ⅝ in. pitch. The screw is held secure, as the lower part of the nut sets in the 4½ in. hole of the collar block. To provide a suitable bearing for top of screw and to distribute the load of screw evenly over cross timbers cast iron caps are used, these caps are 6 in. by 8 in., having a slight recess on one side to take the projection of the top on the screw.

The screw as described above is the one used largely and is called a five ton screw, but where heavier loads are to be raised and limited space for setting screws, the cut steel screw of 20 ton capacity is used. This screw is made from 4¼ in. round steel, thread being 3-inch diameter with a pitch diameter of ½ in. The screws are turned by means of turning bars, which are usually about 5 ft. in length made of good grade of steel and slightly bent about a foot from one end. This bend gives the operator a better opportunity to work the screw.

The collar blocks are made either of steel or wood, if steel a 9-in. channel, 1-ft. 6-in. long is used. Wood collar blocks are made of hard wood usually 4-in. maple, 10-in. wide and 18-in. long and riveted close to either end to prevent splitting. The collar blocks have a hole about 4½ in. diameter in which sets the nut of screw while flange of nut bears on collar block.

The above described equipment is used in raising a structure. In preparing a building for moving after it has been raised to the required height we lay 6 by 8-in. oak runs, about 16 ft. in length, set on blocking. These form the lower bearing for the rollers. The rollers are usually made of quartered maple either 6 or 8 in. diameter and 4 ft. in length.

Roller plank is made of 3½ or 4 in. by 12 in. maple 4 ft. long, tapered at ends to permit of easy starting of rollers. They are riveted at either end by ¼ in. rivet with washers. When the structure is ready to be moved blocks or pulleys are rigged up and by means of either the winch or capstan the structure is moved as required. The pulley block is a wonderful advantage in reducing power. It may be the ancients were familiar with it and made use of it in their work, we cannot trace the block to its origin, so it is quite likely they were conversant with its use.

Until recent years, the heavy 1½ in. and 2 in. manila rope was used in moving structures while at present a rope with a steel center and manila covering is generally used for heavy work, a ⅝ in. line of this type being more than equivalent to a 2 in. manila line.

In preparing a building or structure of any kind for raising and moving it will be necessary to make a careful study of the structure. The weight should be carefully estimated, the general construction of the building should be understood, in order to know the distribution of loads on present foundations. The character of ground over which structure is to be moved should be considered, especially if of a heavy type.

After the above points have been carefully considered a layout is made showing the manner of picking up the structure, which is done in the case of brick or stone structure by inserting either beams or heavy cross timbers at proper places to take the load without causing strains in the main structure, when the building is raised. The main principle in raising structures is to keep conditions as nearly as they were, when on original foundations.

In the case of steel structures special consideration is given to each individual case and no set method can be laid down for their work, however, the general principles are applicable to all structures.

The following sketch shows the manner of building a blocking and the setting of timbers and arrangement of screws for raising a structure. See Fig. 1.

From this one sees the regularity and care taken in building the blocking and the manner of setting the screws and locating cross timbers for taking up the building.

After the building has been raised the required height and it is desired to move it, oak runs are built and the building lowered on rollers which bear on 6 by 8-in. oak runs below and on roller plank above, after which screws are removed. This is shown by the following sketch, Fig. 2.

In case it is desired to turn the building slightly the rollers can be "cut", that is, set at a slight angle to the general direction and gradually be brought over to proper line. Where

the building is to be given a quarter turn, a half turn or a complete turn, a pivot point is selected and runs laid and rollers set to operate about this point. See Fig. 3.

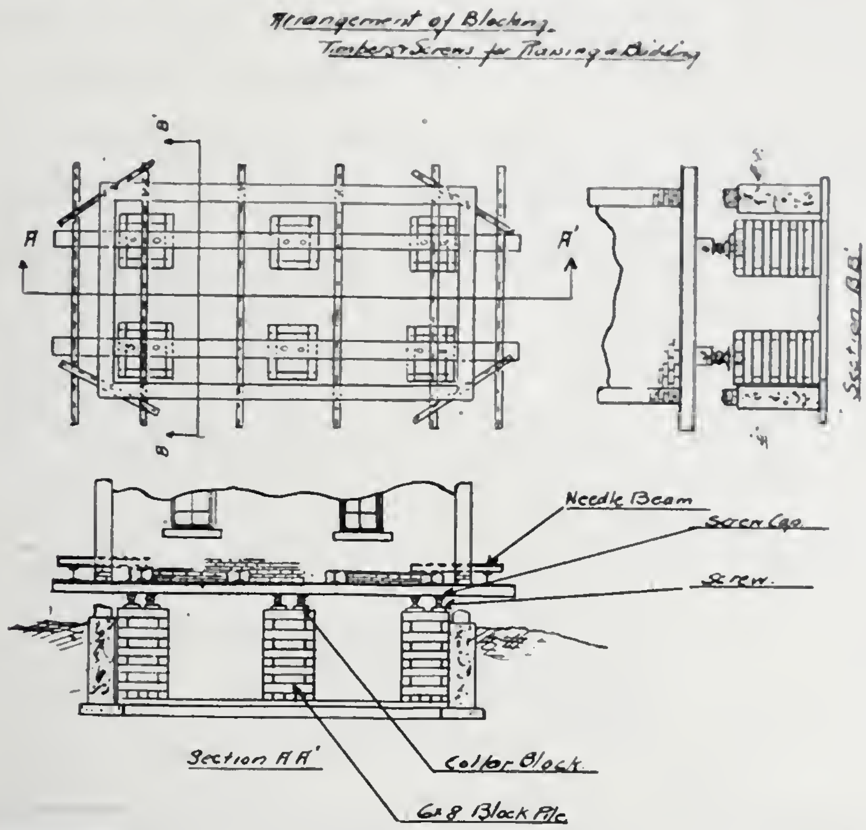

Fig. 1. Arrangement of Blocking, Timbers and Screws for Raising a Building.

In the alteration of buildings such as the change in fronts or shoring of floors or the supporting of any heavy structure where high blocking would be required, pump logs or drums

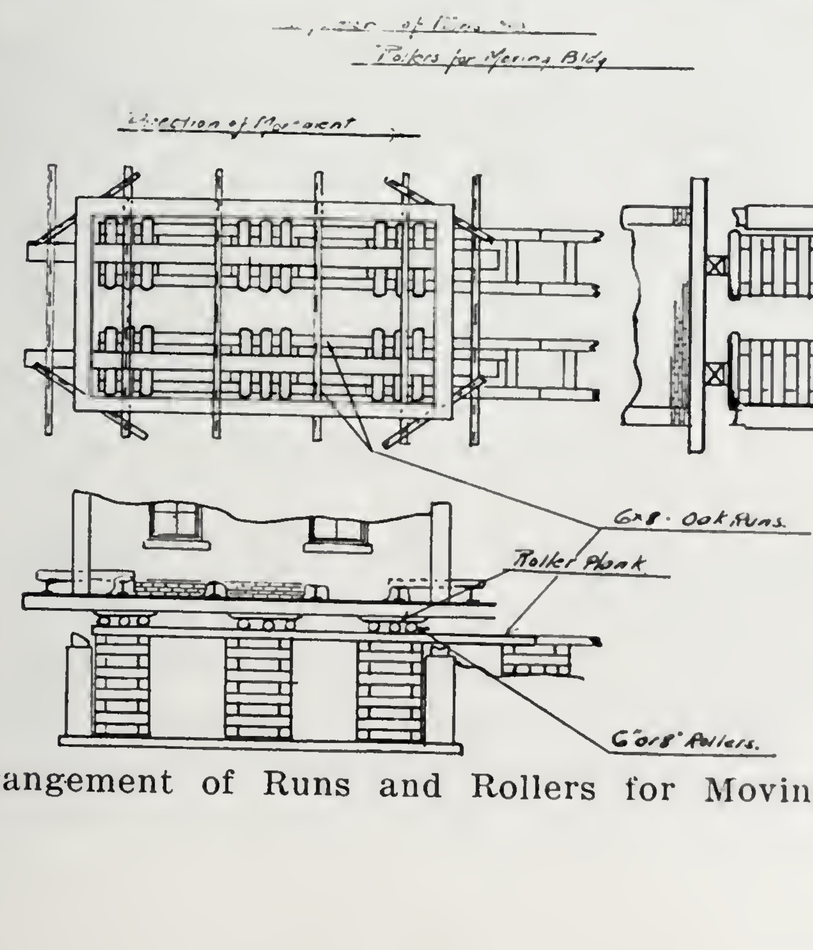

Fig. 2. Arrangement of Runs and Rollers for Moving a Building.

are used instead. Pump logs are timbers, usually 8 in. by 8 in. in size, but often larger, one end of which is bored to a 4½ in. diameter about 18 in. deep. In this hole operates the screw, the lower part of nut sets in the 4½ in. hole of timber and the flange of nut bears directly on the bottom of timber,—more often a collar block is used to form a bearing for the nut. Drums are usually set in position with the screw at the lower end, so that the screw can be more easily operated.

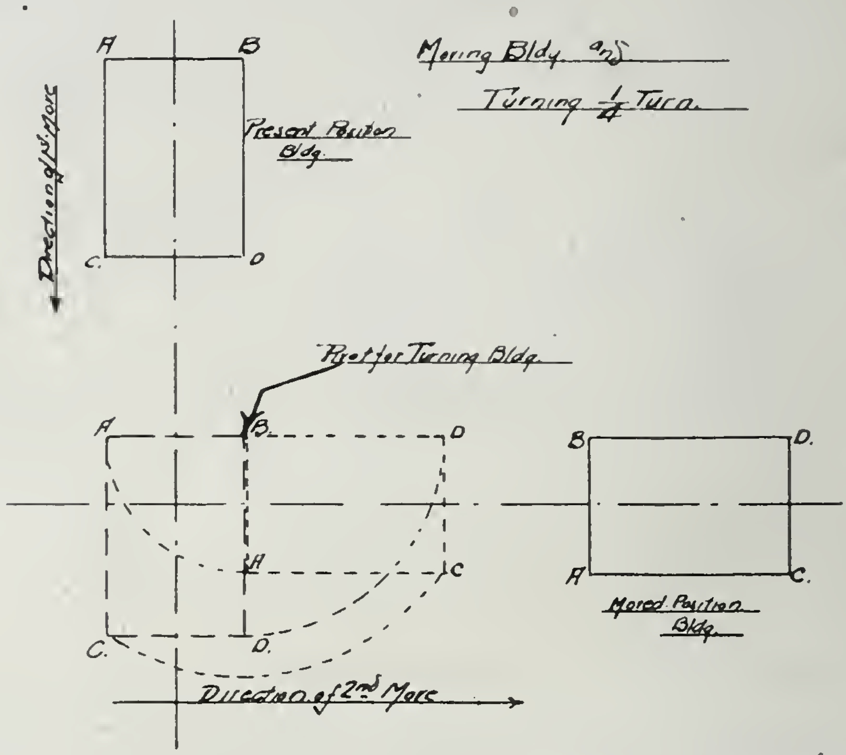

Fig. 3. Plan Showing Arrangement for Moving a Building and Turning ¼ Turn.

We shall now consider a few of the more interesting contracts which have been completed, which will give some idea of variety and character of the problems, which we have to consider from time to time.

SUPPORTING, RAISING AND BRINGING TO LINE THE SOUTH 22ND STREET BRIDGE WHILE THE TWO RIVER PIERS WERE REMOVED, AND REBUILT.

The South 22nd St. Bridge of Pittsburgh was opened to traffic in the year 1897. The structure consists of a 520 ft. river or channel span with two approach spans of 260 ft. each. The bridge trusses are 32 foot on centers. The roadway is 27 ft. in width with two sidewalks of eleven feet each. The roadway and sidewalk on entire bridge has buckle plate construction,

with concrete walks and concrete roadway base, making an exceptionally heavy floor.

It was but a short time after the bridge was opened that a settlement in the river piers was discovered. These piers were built on a wood grillage made up of 12 by 12 in. timbers, with-

Fig. 4. South 22nd St. Bridge. Temporary Lifting Device and False Work at Channel Span in Place at South Pier.

out pile foundation. This settlement continued for several years when in 1907 it was decided to try to better distribute loadings of bridge over a larger area on the piers, thus hoping to prevent further openings. This was to be done by running seven girders 4 feet deep under shoes of bridge. This was,

indeed, a difficult proposition as it required the disturbing of the bearing about the shoes as the stone was cut away to permit placing of the girders. Before the above work was commenced, a clamping device was placed about the tops of piers. This consisted of a series of beams bearing on ends of piers close to the top and clamped together by means of long rods. Work was then commenced cutting out for girders, one girder was put in place, but the real condition of pier was then seen and it proved to be so serious that work was stopped and the contract cancelled.

A second method was then considered which provided for driving sheet piling about the wood grillage of piers and drilling numerous 4 inch holes in the piers extending well to the bottom, and filling them with cement grout. By this it was hoped that the cement would fill up the numerous crevices, of the pier and run well in and around old grillage. After the completion of the cofferdam, work on pumping out was begun and continued for several days, when a further settlement of the pier was discovered. It was then that the city appointed a commission of the following prominent engineers: Hermann Laub, Thomas H. Johnson, and E. K. Morse, to examine the conditions at the bridge and report with recommendations.

In this report they stated that the bridge was in an extremely unsafe condition and recommended that the two river piers be removed and replaced by new piers on pile foundations.

Plans were drawn up and specifications prepared for the support of bridge and the reconstruction of piers. The Dravo Contracting Company of Pittsburgh were awarded the contract for this work. The building of false work and supporting of the bridge while piers were removed and replaced was sub-let to the Eichleay Company. Mr. Hermann Laub, a former member of the commission was retained by the Dravo Contracting Co. and the Eichleay Company as consulting engineer for this work. It is to Mr. Laub that much credit is due for the method under which this work was pursued.

The following novel method was used in the supporting of this bridge. The ends of the 520 ft. trusses were suspended from two steel lift trusses which spanned the old pier and were

supported by false work on either side of pier. The false work was built so as to give plenty of space, about the old pier for the building of a cofferdam.

The estimate as to the loading on false work was assumed at 2000 tons, of this 1500 tons was to be taken care of by the lifting device while the loading from the 260 ft. shore span was taken care of by a separate scheme. The 260 ft. span, being of a double Warren type, could be treated differently. It was caught up at the second top chord panel point from the pier and supported by special falsework.

Fig. 5. South 22nd St. Bridge. False Work at South Pier on Rollers Ready to Lower.

The lifting device consisted of simple triangular trusses of 66 ft. span with a depth of 23 ft. 6 in. Each truss was designed for a load of 1 500 000 lb., top chord stressed to 12 000 lb. while the eye bars were stressed to 18 000 lb. per sq. inch.

The trusses were securely built about the members of the bridge trusses, the bottom chord eye bars of the temporary trusses were just above the sidewalk level, the center eye bars suspended from pin at apex of trusses consisted of 4-12 by $2\frac{1}{16}$ in. eye bars. The two outer bars were attached to ends of 12 in.

pins which were the lower chord pin of the 520 foot span. This pin was provided with a special nut which gave the required bearing for bar. The two inner bars were shorter and at their lower ends were connected to two smaller and shorter eye bars of an equal area which were attached to pins through the two nickel steel lifting beams which passed through the main shoe of the bridge. These lifting beams the size of which were 6 in. by 18 in. by 7½ ft. between centers of eye bar pins, were stressed to 30 000 lb. per sq. in. The two trusses were connected at the apex by a strut and also at bolsters to take wind stress.

The bolsters or shoes for temporary trusses set on a series of grillage beams arranged to distribute the loading uniformly over three lines of 2-12 by 12 in. timbers each. These timbers were of sufficient length to extend under the two bolsters, thus helping to tie the two bolsters well together. Below these lines of timbers were arranged screws, about 100 being placed under each shoe. The screws set in iron collar blocks and were supported by steel *I*-beams which set directly on oak timbers of falsework.

There being no girder at pier to carry stringers it was necessary to support end of stringers by running beams under stringers between main shoes and catching these beams at midpoint with rods attached to a hanger suspended from peak of temporary trusses.

The arrangement for picking up the ends of the 260 ft. span was more simple. A tower of 4-12 by 16 in. timbers, well braced, was extended to second top chord panel point where, by an arrangement of beams, bearing on the chord pin was secured. The 4-12 by 16 in. timbers set on shorter frame work of 12 by 12 in. timbers which extended above floor level. These 12 by 12 in. timbers were bored at lower end for screws and in these were placed the 20 ton screws. In this manner the loading was transferred to steel grillage which was supported by thro timbers similar to arrangement supporting lifting device and screws arranged to carry same.

When the screws were all set and lifting device in place, except for the outer bars which engaged the main bridge pins,

a strain was placed on lifting device equivalent to one-half of the load for which it was designed or full load on inner bars. Before any strain was placed on the lifting device distances were measured accurately on the bottom chord eye bars and the two inner vertical bars, the elongation of these members under the assumed loading was calculated and the distance laid off on bars. Measurements were taken from time to time as the screws were being operated and when the bars were found to have elongated the required distance under the assumed load-

Fig. 6. South 22nd St. Bridge. Removing South Pier.

ing the raising was stopped and measurements were accurately taken from the centers of pins at top of auxillary trusses to centers of main 12 in. bridge pins. These four measurements were found to be very close, within ¼ in., so it was decided to average the measurements, allowing for the elongation of these bars under their full load and deducting from the measured length the elongation. The plank end of bars were then ordered to be drilled. When these bars were put in place the strain having previously been removed from lifting device, work on the raising was resumed. Measurements of bars for elongation.

under full load were taken from time to time as the bridge was raised, the readings proved the accuracy of the assumed loadings coming on the lifting device.

There was an uneven settlement of the north river pier of about five inches, the upstream pier having a settlement of 17 in. while the downstream 12 in. This caused a movement of 11 in. in horizontal direction of the centre line of bridge, causing serious strains in the top chord bracing and other members, some of them having buckled. The bottom chord eye bars of the 260 ft. span in the first panel from pier, were buckled on the downstream side while those on the up-stream trusses were found to have elongated ¾ of an inch—which was beyond their elastic limit and consequently when bridge was brought to grade and alignment a buckle in these bars were apparent. By forcing a diaphragm between the two bars tension in bars was again produced.

The bridge was first brought to a level condition by operating the screws more on the low side of bridge after which the screws were operated first on one side of pier then on the other until bridge was brought to proper grade.

The shore span as stated was raised by the 12 by 16 in. timbers together with the steel post at that panel point. In order to take care of the difference in the modulus of elasticity of steel and wood, screws were placed on the top of grillage, and were kept well tightened in order to prevent too much of the load being taken by the steel post.

The bridge was brought to line by setting the screws about a quarter of an inch out of plumb and in the opposite direction to the required movement. When all screws had been tilted slightly it was found that they gradually become plumb, this operation was repeated until finally the bridge was gradually walked over to the proper line.

A portion of this distance was gained during the raising of the bridge, upon releasing strains in bridge. After the bridge was raised it was held on the lifting device for several days in order to make certain that everything was perfectly safe.

The pier was then removed and replaced by new pier built on 175 piles driven to refusal. After the bridge was lowered

to new pier the lifting device was removed and installed at the south pier and work was similarly done as on north pier. The falsework was moved on flats and towed over to the south pier and moved on falsework piling without taking apart. This meant a big saving of time in this work.

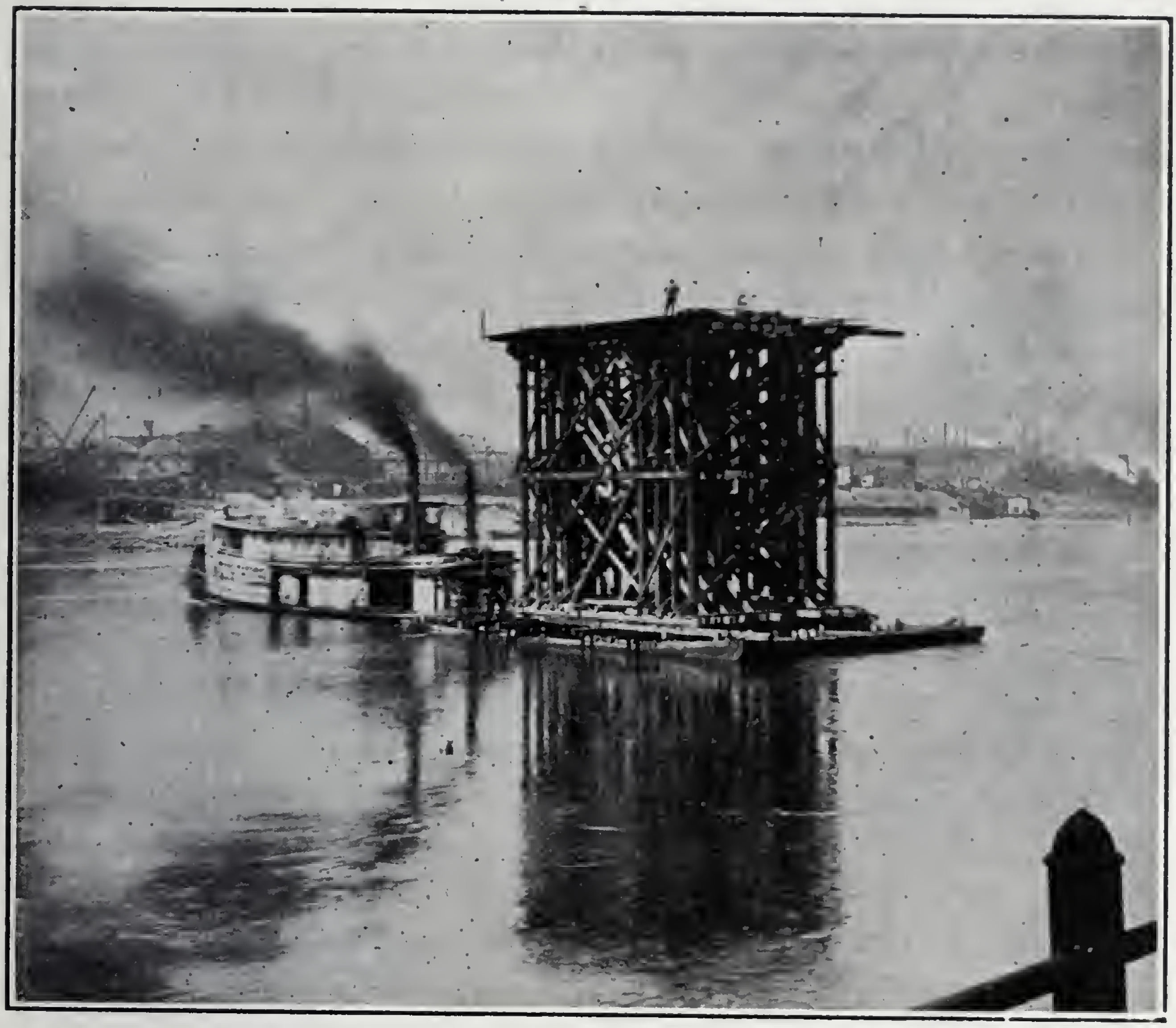

Fig. 7. South 22nd St. Bridge. Moving False Work from North Pier to South Pier.

The time required to complete the work on the two piers was nearly two years, the work was completed without any serious difficulty, the lifting device proving entirely satisfactory for the work.

MOVING A 100 FOOT STEEL STRUCTURE FROM TEMPORARY ABUTMENT TO PERMANENT ABUTMENT.

The truss span over the B. & O. R. R. tracks at the approach to Glenwood Bridge was recently replaced by a new span of a much heavier construction.

The span is approximately 100 ft. in length and weighed nearly 100 tons. The steelwork consisting of the floor beams, stringers, and bottom chord together with the web members below the floor level were caused in concrete. This concrete increased the dead load of structure to over 200 tons.

The contract with the Pittsburgh Railways Company called for the erection of this bridge complete without the interruption of traffic more than three days. It was therefore quite necessary for the new bridge to be erected alongside of old structure and then moved into place after the old bridge was dismantled.

The sidewalk brackets were first removed from the old span in order to locate the new structures as close to the old site as possible. Temporary abutments for new structures were provided by building extensions to main abutments of blocking and of sufficient length to set new structure. This being a skew bridge the temporary abutments were much wider than the width of the bridge.

Midway between abutments and between the tracks of the B. & O. R. R. a wood bent was erected, the same height as the temporary abutments, extending from either abutment. Resting on this bent were two pairs of 20 in. by 65 lb. *I*-beams approximately 60 ft. in length, 6 by 8 in. runs were laid over these beams and continued out on the ground. The trusses were assembled and riveted on these runs. As the trusses were completed rollers were inserted and the trusses were finally rolled across the 20 in. *I*-beams by means of an arrangement of tackle, the derrick being used only to keep trusses in an upright position. The derrick was of 20 ton capacity but as a matter of precaution this method was pursued, the weight of a truss being close to 20 tons. After the trusses had been moved out on temporary abutments and moved apart a sufficient distance to permit of the erection of floor beams and stringers, the erection of the steelwork was then completed and the work of encasing floor system begun. Upon the completion of the concrete work the ties and sidewalk were laid.

Attention was then directed to the dismantling of the old structure, the traffic was closed, cars running as close to either abutment as work would permit. Temporary approaches were

built to the sidewalk of new structure, which was used only for foot traffic. The old structure was soon cut apart, the oxygen burner was used to good advantage in this work, and removed from site by the derrick.

Upon clearing the site runs were laid on abutments of the old structure, rails were set on them, and brought level with the rails of temporary abutments, shorter rails were placed under the shoes of the trusses, thus providing a good bearing top and bottom for the $2\frac{1}{2}$ in. diameter steel rollers which were arranged under each shoe.

Fig. 8. Glenwood Bridge. Arrangement of Blocking, etc.

Two sets of blocks rigged 3 and 3 were attached to a shoe of the truss on either end and the blocks arranged to move new structure in the direction desired. The hoisting engine was used to furnish power in operating blocks. The movement was accomplished in about an hour, somewhat longer time being required on account of the necessity of changing hitch of blocks. Drums were set close to the abutment on one side and screws were also set on false work which had previously been erected

between tracks and brought up close to the bottom chord and structure raised slightly on one end to allow the removal of the rail, rollers and runs, after which that end was lowered to place. Drums were then set at the other end and in a similar manner the bridge was lowered to the abutment. The new tracks were laid on bridge and planking on new span together with a portion on adjoining approach, which was renewed. When the approach span was uncovered the condition of this steelwork was such as required considerable new steel, the delay in obtaining additional steel together with considerable grading and changing of tracks at the approach to new span caused a delay in opening traffic on bridge, so that it was nearly six days before cars were running over the new span.

MOVING THE ERIE RAILROAD CAR DUMPER, CLEVELAND, OHIO.

The location of a pier for the new Detroit Superior Viaduct at Cleveland destroyed the usefulness of a Car Dumper owned by the Erie Railroad and used for the loading of vessels with bituminous coal for points on the Great Lakes.

It was decided to move the Car Dumper a distance of 214 feet along the river front to new foundations, which would be entirely clear of all viaduct interference.

The contract for this work was awarded on January 21st to the John Eichleay Jr. Co. Under their proposition the dumper, boilers and machinery were to be moved as a unit onto their new foundations. Time was a very important factor in the letting of this work, all other bids received contemplated the dismantling of the entire structure and re-erecting.

The car-dumper was of the Wellman-Seaver-Morgan type and was comparatively new, having been erected in 1911.

The car dumper superstructure when the pans were elevated was 116 ft. high, 38 ft. 6 in. wide and 56 ft. long. The main structure is carried on four columns, the loading on the two front columns when the pan is elevated and car cradle suspended is about 250 tons; while the two rear columns carry about 80 tons.

When we consider the entire proposition including the boilers, brick work, engines and machinery along with the

Fig. 9. Arrangement of Blocking for Moving Car Dumper at Cleveland, Ohio.

dumper it meant the moving of a structure 40 ft. wide by 110 ft. long and 116 ft. high and weighing approximately 800 tons a distance of 214 ft.

In moving this car dumper it was necessary to move over a dock platform nearly 100 ft. long by 28 ft. wide. This platform was built on bents of piles spaced six feet apart, each bent being made up of five vertical and three batter piles.

The material to the rear of dock platform was of a hard clay retained by sheet piling built against the ends of the pile bents. The problem of moving the structure over this platform safely was the one which seemed to give the greatest concern. It only meant however, that if the loading could be evenly distributed over piling, no danger would be encountered. It would mean only a loading of about 10 tons per piling, which was amply safe. The batter piling could then be used to retain clay back of platform.

The manner of proceeding with this work was as follows:

The structure was prepared for raising. This was done by clamping 2-24 in. by 80 lb. *I*-beams about 16 ft. in length to each of the two main front columns and extending cross wise of the structure, the bottom flanges of these beams caught up the underside of column bases, making a secure clamping and holding device. The other columns were caught up by means of clamping 12 by 12 in. timbers to either side; a system of timber grillage was installed which carried the engines and machinery arranged in such a manner that the greater part of the loading would be thrown to the rear of the structure.

The brick work encasing the three Stirling Boilers was raised by means of steel *I*-beams, a rigid frame especially provided for this work having been used. After the above preliminary work was completed the entire structure was raised a distance of nearly three feet, in order to allow clearance for the building of the runs and the placing of rollers. As an additional precaution in throwing more weight to rear columns the front columns were elevated 6 inches higher than the rear.

Under the 24 in. *I*-beams and running longitudinally of structure 12 in. by 31½ lb. *I*-beams were placed thus forming the

top bearing for the rollers on the outer set of runs between two front columns.

The other two sets of runs, that is the center and rear together with runs supporting the coal pockets had for the top bearing of rollers 12 by 12 in. timbers. Blocking was used under each of the three lines of runs and brought to proper height for rollers.

Fig. 10. Arrangement of Runs and Rollers for Turning Building at Glens Falls, N. Y.

On the dock platform blocking was built up over each bent and on these and directly over bents were placed 20 in. by 65 lb. *I*-beams, which were 30 ft. in length and extended under the middle set of runs at rear of platform and set on high piling at front of dock, the piling, having previously been cut off level with the old concrete. The beams were braced to prevent shifting or overturning.

Upon these 20 in. *I*-beams were placed 12 in. by 31½ lb. beams running the full length of dock and resting on the con-

crete at either end, these beams forming the bottom bearing for the front set of runs. For the center and rear runs over the platform 12 by 12 in. timbers with blocking of sufficient height for 6 by 8 in. oak runs were used.

The structure was lowered on rollers after having been raised to the proper height, and by means of two winches and two sets of blocks rigged 5 and 5 the structure was gradually moved over to new foundations. Horses were used to provide the necessary power.

It was found necessary to "cut" the rollers slightly on account of the new location not being in a direct line with the old. When the structure was over the new foundations, the screws were again set, the rollers and runs were removed and the structure lowered. There were 250 anchor bolts in the new foundations and no special difficulty was had in catching them.

It took only 22 days from the time the material arrived at the site to prepare the structure for moving. The raising, moving and lowering of structure was accomplished in 8 days. It was found on taking levels on the platform over which the structure had remained for a night that a settlement of only 1/4 of an inch had taken place and this was more than likely in the compression of the timber and blocking.

The steam pipes from boilers to engines were not disconnected during the moving, a careful examination of brick work, supporting boilers proved that no cracks had developed.

The moving of the boilers with the brick work was thought by boiler people to be quite impracticable and consequently was watched by them with critical eyes.

The above contract was completed and material shipped to yard by March 15, within 40 working days of the arrival on the ground.

MOVING AND TURNING A LARGE THREE-STORY OFFICE BUILDING.

This building was owned by the Glens Falls Insurance Co. and was located at Glens Falls, New York. It was removed from the old site to provide room for a new office building. The building was 60 ft. by 105 ft. in size and was of three-story

construction with heavy 16 in. walls, a heavy vault with 28 in. walls formed part of the construction.

This building weighing approximately 2600 tons was raised two feet, then turned thru 90 degrees, moved across the street between two other buildings and lowered two feet to proper level.

The first step in connection with this work was the placing of the 12 in. by 31½ lb. *I*-beams, crosswise of the building, holes

Fig. 11. Building Turned and in Position to Move in Direct Line Across the Street to New Location in Glens Falls, N. Y.

were cut in the walls below the first floor and these beams which were from 50 to 65 ft. in length were set in groups of three and spaced about 5 ft. on centers of groups. These 12 in. *I*-beams were set on five lines of 12 by 16 in. timbers which ran longitudinally of the building, one line of timbers was placed at the center of the bulding and one inside and outside of the two side walls.

These timbers set on about 400 jack screws of 10 ton capacity which in turn set on wood collar blocks, bearing directly on top of the five lines of 6 by 8 in. blocking.

The end walls and cross walls were picked up by means of 10 in. *I*-beams, which beams were set on the 12 in. by 31½ lb. *I*-beams which crossed the building.

Fig. 12. Building Being Moved Across a Main Street in Glens Falls, N. Y.

The building was then raised about two feet and prepared to turn. Additional block piles were built and 6 by 8 in. runs were laid spaced about 2-feet apart and similar to chords of an arch concentric with a 6-inch cast iron pivot ball which was the center of rotation and which was placed between two plates. By shifting the screws the 8 in. rollers, of which there were about 500 in number were set in place on runs provided, bearing on the roller plank above which bear against the 12 by 16 in. timbers and the cross 12 in. *I*-beams. These rollers were radial to the pivot ball. After they were set the screws were lowered and load transferred to rollers and then by means of tackle and

capstan and a team of horses the building was slowly revolved the required distance. This was a tedious and slow operation on account of delay in "cutting rollers"—this operation required two weeks time.

After the building had been revolved the required distance it was again prepared for raising by placing screws under the structure and releasing the rollers which were removed. Five new runs were then prepared and the rollers were again inserted and load placed on them. The building was then moved across street. Care was required in moving the building as the rollers were cut slightly to miss the corner of an adjoining church.

It took 8 days for this moving operation, only a small portion of this time was actually used in moving. The greatest distance traversed in one day was about 65 feet. As the structure was moved into new site the building was built up on high block piles due to excavations for basement. These blockings were nearly 13 feet high. After lowering two feet to proper height the building was located in its new position and walls were built up and timbers and beams removed.

The tackle used in moving this structure consisted of two sets of blocks rigged 7 and 7. A chain was thrown around the 12 by 12 in. timbers to the front of building which had bearing on ends of the 12 by 16 in. timbers. The other block was pin connected to two sets of two eye bars each which were attached by means of pins to two channels having a 4 by 12 in. timber between them and bearing directly on the 12 by 16 in. timbers at the rear of building. The last line of each set of blocks was taken to the capstan which was operated by a team of horses. It was estimated that the necessary power required to move structure was close to 150 tons.

The time for the completion of this work was about 60 working days with 40 men per day. An examination of building showed it to be in perfect condition, no cracks or other evidence that building had been strained could be discovered.

DISCUSSION.

Mr. A. Stucki: I did not understand one expression, where he spoke of "cutting" the rollers. I thought he meant to make them conical, but I judge that is a mistake.

The Author: "Cutting" the rollers is a term used in our work meaning the knocking of one end of roller slightly with a hammer to change the general direction of structure being moved. It is true, however, we find it necessary at times to cut rollers with a saw.

Mr. Elmer K. Hiles: There is one very interesting point that Mr. Nichols did not bring out, in connection with moving the car dumper at Cleveland, and that is the great care the Eichleay Company took to avoid a shut down of operations of the dumper in case they met with an accident. I think he might enlarge on that point.

The Author: Under our contract for the moving of the car unloader at Cleveland, there was a penalty clause and a liberal bonus if work was completed on or before a certain date. In order to protect ourselves against the loss of this bonus money, which we anticipated, two complete sets of detail drawings were secured covering all structural material, machinery and boilers to be moved. One set was left at the job while the other set was sent to our office. In case a break occurred on any part even to a bolt such part could be ordered and put in place in the quickest possible time. We did not experience any accidents whatever, in the breaking of any part of the structure. The work was completed one week before the time set in contract, for the procuring of bonus money.

Prof. H. R. Thayer: This is a very interesting paper. I would like to ask something about the method of attaching ropes to the building. It seems to me that would involve a great deal of care in handling a masonry structure. Of course a well braced steel structure would hang together, but in dealing with masonry all engineers understand it is an entirely different matter. I would like to know how they arrange the pull on the rope and what method is taken to brace the frame work, or

whether they rely entirely on the uniform movement of the structure.

Another point is whether Mr. Nichols can give us the values he uses in designing his timbers and steel work for this duty, and if he can tell us something about the pressure that is due to a brick wall. That is one of the things about which there is more or less argument and dispute among engineers and more particularly in the line of bolted joints. We have very little information of that sort and in handling emergency matters like these I know he has to meet cases of actual failure of material and he is in better position to tell us what these stresses are than other engineers, where a failure means a pretty serious matter. If we put up a bridge and it fails we do not know oftentimes whether the stresses we are using over and over again are safe or too far on the side of danger. I imagine he can tell just where the danger line lies, handling such timbers and having met at times with unusual stresses.

The Author: In the moving of brick structures great care is required to keep the building level and the movement uniform. It is usually customary to run cables entirely around the building and tighten by means of ratchets.

In attaching the ropes to take the blocks for moving a brick structure these are not connected directly to any part of the brick building, but to the timber or steel grillage upon which the building sets. Thus the weight of the building is used as anchorage for holdng timbers secure where ropes are attached.

In the case of the Glens Falls work, heavy timbers run longitudinally the entire length of the building and resting on these timbers were beams spaced about five feet apart. These beams took the direct load of the building. These timbers were cut off at rear end of building to secure an even bearing for the steel channels which bear directly against the ends of timbers. To these channels two sets of heavy blocks were attached—one block of either set being attached to timbers at the front of building while the other block was attached to the channels at rear of building, the last line of each set of falls was then

brought to the front and attached to horse crab at the front of building.

In our experience steel structures rarely fail under less load than what is usually allowed by reputable engineers—compression members are more common in failure than tension members. Failures are usually due to increased loadings, which are far beyond that which structures was originally designed.

Mr. W. E. Snyder: It has always been sort of a mystery to me how you managed to get the building up off the foundation and keep on raising until you get to the desired height, with such a structure as brick and masonry, without cracking it, getting one end a little ahead of the other and getting it twisted enough to produce cracks, especially where you have so many men to deal with and a good many jacks under the building.

The Author: The building is watched carefully by all the men to assure of the raising in a level position. These levels are procured by means of ordinary carpenters spirit level which is placed on runs and timbers which support the structure and kept as near level as possible.

Mr. Emil Danenhauer: In raising the building a number of screws are divided among the men. Each man may have ten screws to turn. Each man takes his screws and makes two rounds on a given signal. He starts at one end and makes a quarter turn and goes through to the end of his screws, and then returns and stops until every one else is through and until the signal to turn is given again. Then of course beside that we use the level on the runs and the timbers supporting the building to see that they are kept level.

Mr. A. Stucki: I noticed in McKees Rocks what looked like a troublesome job—the raising of half of a brick building.

The Author: As for the raising of half a brick building it would only be necessary to provide supports for the walls along line where building is cut, these supports would be in the nature of drums, extending from roof to basement.

Mr. Hermann Laub: I have had quite a number of structures, principally bridges, to move, lift and readjust dur-

ing the last 20 years. One of my first jobs was the readjustment of the 7th Street Bridge over the Allegheny River in Pittsburgh. The anchorage on the Allegheny side of this bridge settled and gave somewhat, which (this bridge being of a suspension type) shortened the distance between the Pittsburgh and Allegheny anchorages about 5½ inches and distorted the cable chains at the middle of the channel spans. To get these braced chains in their proper location, it was necessary to pull them 5½ in. in the direction towards Allegheny. A new anchorage, back of the existing one in Allegheny, was built with new anchor chains. After this was done the eye-bar chains at the Allegheny side were disconnected from the anchor chains of the old anchorage and by means of pulling rods connected to the new anchor chains and cable chains, hydraulic lifts applied in the center of the channel spans on a few wooden trestle bents built for that purpose, the whole bridge was then connected within 36 hours. This was done in the fall of 1896.

Another work of this kind was the raising of the Boston Bridge near McKeesport over the Youghiogheny River in 1899. This bridge is a cantilever construction, with a 350 foot channel span and two 175 ft. end spans. On the McKeesport side it had a bad grade crossing, the grade of this end span being 5 percent and the B. & O. R. R. tracks being on a sharp curve. I was directed to make an overhead crossing and for this purpose it was necessary to lift the bridge on the pier nearest the B. & O. R. R. about 17 ft., to give the railroad the necessary clear head room of 21 ft. I worked out a plan, to raise this bridge right from the stone pier and build up gradually underneath with steel grillage laid in concrete. I asked for bids, but the bridge companies were not anxious to do this work. So I took the contract myself with the stipulation to have the raising done in 10 days. The first day we only lifted it ½ inch, but the second day we raised it up 33 inches and in 9 days the whole lifting was completed.

The repair work of the 22nd St. Bridge in 1908-1910, with which I was connected and which was just so ably described by Mr. Nichols was perhaps one of the riskiest pieces of bridge work done in this part of the country, considering the limber

superstructure itself, the danger from ice and drift on the temporary piers and the maintaining of the traffic for a period of a year and a half.

Outside of bridges, it may interest to mention the reconstruction of the Homeopathic Hospital on Center Ave. in 1908. This building, which was built partly on clay, settled as much as one foot during 24 hours at some places; the foundation walls moved inside at their bases and for some time it looked as if the building might collapse. By quick action and spreading these foundation walls apart by timber and screws on the floor of the cellar, a collapse was probably prevented. All this work as well as lifting of the building walls to their proper level, so as to remove old foundation walls and put in new ones, was done by John Eichleay, Jr. in the manner as described by Mr. Nichols in his paper.

Mr. T. J. Wilkerson: My personal experience with the raising or moving of structures is very limited; the only one with which I have had any connection being the South 22nd St. Bridge. At the time this work was done I was connected with the Division of Bridges, City of Pittsburgh as Assistant Engineer and had the pleasure of looking into the design proposed by Mr. Laub and checking up its strength.

I notice one point in Mr. Nichols' paper regarding this bridge that I don't think he clearly described, that is, that the 260 ft. span and the 520 ft. span were connected to the same shoe with separate pins, making it necessary to raise both spans together to prevent tipping the shoe and it was not possible to attach both pins to the raising truss without a possible end thrust which would have been risky. It was also necessary to support the greater part of the weight of the 260 ft. span at the top chord point, owing to the weakness of the truss post at this point. It is my opinion that the plans followed in raising and supporting this bridge were as good as could be used for the work.

MEASUREMENT OF THE VELOCITY OF FLOWING WATER

By Lewis F. Moody*

Discussion by Messrs. Gardner S. Williams, N. C. Grover, Clemens Herschel, William Kent, Edward S. Cole, Morris Knowles, Thomas P. Roberts, Charles M. Allen, Robert Linton, Herman Bacharach, F. Nagler, E. H. Brown, J. S. Beresford, John N. Chester, Lewis F. Moody, and Benjamin F. Groat.

INTRODUCTION.

One of the most important subdivisions of hydraulics is the measurement of flowing water. The various methods in use for such measurement may be separated into three classes:

1. Direct measurement by volume, or by weight.

2. Measurement of a difference of elevation, or pressure drop, between two points in a stream, from which the discharge, or the average velocity at a section of the stream, can be determined from known relations. This includes weirs; the Venturi meter; standard orifices or calibrated nozzles; measurement of slope of hydraulic gradient, or gauge height, of an open stream, or of difference of pressure across a pipe bend.

3. Measurement of the local velocity at various sections of a stream, and determination of discharge by integration of the product: *area* × *velocity* of each section.

A method not included in any of these classes, which may be worth mentioning, is the introduction of a known amount of chemical with the water to be measured, and determination of the amount of the substance per cubic foot of the resulting mixture.

For the accurate measurement of large quantities of water,

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the first method can sometimes be adopted by the use of a close-fitting apron, or screen, filling a flume of rectangular section, and moving through the length of the flume. The second method can be applied to large discharges by the use of weirs or spillways having known coefficients. In most cases, however, where flows of considerable magnitude must be handled, the only method which can be used without building expensive structures is the third; and in many cases where small discharges must be measured in closed systems, as in water mains or boiler feed lines for instance, this method is the only feasible one. The present paper will be confined to this method.

MEASUREMENT OF VELOCITY

The principal methods of measuring velocity are by means of:

1. Current meters of the mechanical type.
2. Rod or subsurface floats.
3. The hydrometric balance.
4. The Pitot tube.

The first method is probably the one in most general use. The most recent developments in the use of current meters have been described by Mr. B. F. Groat in a valuable paper "Cup and Screw Meters"[1] and will be referred to here only when it is desired to compare the performance of current meters and Pitot tubes. The rod float method may be applied under favorable conditions in open channels of uniform section, but can rarely be relied on for an accuracy of one percent.

The third method, which would seem to the writer to offer considerable promise, depends upon the measurement of the pressure exerted by the water against a plate held normal to the current. Since this method has not been developed in modern practice, it will not be treated here on account of the few data available. The fourth method, the use of the Pitot tube, is perhaps capable of more general application than any of the others, and furnishes one of the most useful tools which the engineer can command.

[1] "Characteristics of Cup and Screw Current Meters," by B. F. Groat. Transc. Am. Soc. C. E. v. LXXVI (76), p. 819.

THE PITOT TUBE

Any pipe bent into a direction parallel to the current and inserted in a stream with the end facing the current, may be said to form a Pitot tube. The end may be of a large variety of shapes, but should be in a symmetrical form with respect to an axis having the direction of the current. The pressure created in the tube will furnish a measure of the velocity; and to determine this pressure, gages of many forms may be used. When used in closed channels, the Pitot tube must be accompanied by peizometers to measure the static pressure in the stream; these peizometers are usually connected to a differential pressure gage of the two-fluid type. The fluid used in the gage may be mercury, air under pressure, or oil; depending on whether high, moderate or low velocities are to be measured.

The Pitot tube records a pressure-head exactly equal to the velocity head of the water impinging on it, added to whatever static pressure-head exists in the stream. If the static pressure-head be deducted from this sum, as is done by a differential gage, the result is the true velocity-head h, from which the desired velocity can be found by the relation $v = \sqrt{2gh}$, as will be shown.

The static pressure is sometimes more difficult to determine than the Pitot pressure; although this can be satisfactorily accomplished in the case of a pipe by connecting peizometer tubes to the pipe wall, care being taken that the peizometer openings pierce the inner wall surface without causing projections or irregularities to disturb the flow in the pipe, and that the hole be perpendicular to the surface and be finished flush and with square corners. The pipe surface near the opening should be smooth and regular. The static pressure in an open channel is of course given by the elevation of the water surface, which can be obtained by hook gage in a stilling box or by peizometer connections in the side walls.

THEORETIC BASIS FOR DISCUSSING CONDITIONS IN A FLOWING STREAM

Before taking up the theory of the Pitot tube, it will be advisable to explain a method of determining the conditions at any point of a flowing stream. This method may be used not only for the immediate purpose of this paper, but also for many

hydraulic problems involving the flow in stationary or rotating channels.

Starting with the principle that the force F required to produce in W pounds of water per second an increase of velocity from zero up to V feet per second, or a decrease in velocity from V to zero—that is, the force required to accelerate the water in a tank from rest up to a discharge velocity V, or to retard the issuing jet from V to zero—is given by the relation:

$$F = \frac{WV}{g};$$

let us consider the equilibrium of the tank shown in Fig. 1.

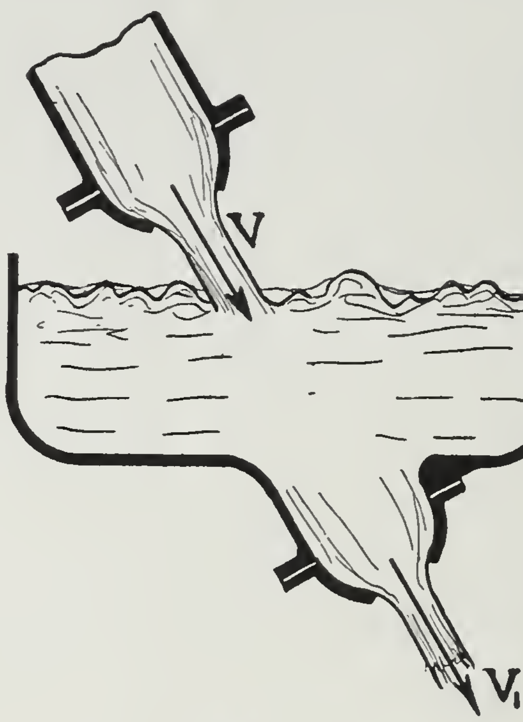


Fig. 1.

A jet of water in which W pounds of water per second are flowing enters the tank with a velocity V; and an equal amount of water is discharged from the bottom of the tank with a velocity V_1. The force exerted by the entering water upon the water in the tank is,

$$\frac{WV}{g}$$

the impulse of the jet; and the force exerted by the leaving water, or the reaction of the leaving jet is

$$\frac{WV_1}{g}$$

The flow being steady, the water which is in the tank at one instant is in the same condition as the water which is in

the tank at another instant; in other words, although the water as it flows through the tank may vary in velocity from point to point in space, nevertheless the conditions at any given point in the tank remain constant with respect to time. Since there is no increase or decrease in the velocity at any point in the tank from instant to instant, the body of water filling this space is in equilibrium and is being acted upon by a system of balanced forces. The force which must be exerted by the sides of the tank upon the water must therefore be equal and opposite to the resultant force exerted by the water upon the tank; which in this case is

$$\frac{W\ (V - V_1)}{g}$$

if V and V_1 are in a straight line.

It should be noted that this result is dependent only upon the weight of water passing through the system, and upon the velocity of entrance and discharge, and is entirely independent of the intermediate conditions of flow. The velocity may be gradually changed from V to V_1 with a small loss of energy, or the entrance velocity V may be dissipated in impact and eddies before the water in the tank is raised to the discharge velocity V_1; that is, the result is not dependent upon the presence or absence of energy losses in the system. It will therefore be unnecessary to modify the results obtained by this method to allow for frictional resistances, or other losses; and it does not matter whether the flow is turbulent or not.

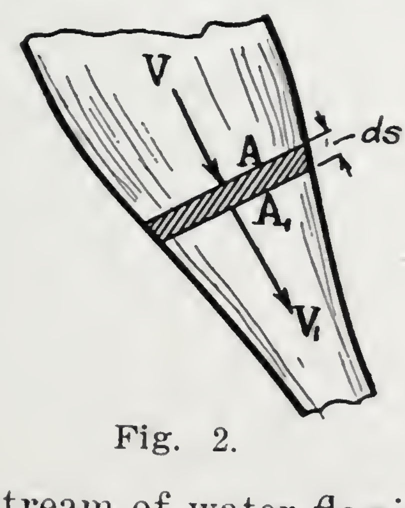


Fig. 2.

Consider next the stream of water flowing in the closed channel of varying section shown in Fig. 2, in which W pounds of water per second are flowing from A to A_1. The flow is assumed to be steady; that is, constant with respect to time.

Consider an elementary portion of the channel of cross-sectional area A and length ds. From the condition of equilibrium of this space, the resultant of the forces acting on its boundary surfaces (and the weight of the contained water) must be zero. These forces are as follows:

On the upstream face, the impulse of the entering water is

$$\frac{WV}{g}$$

and on the downstream face the reaction of the leaving water is

$$\frac{WV_1}{g}$$

as in the case of the tank just considered; in addition to these forces, however, the static pressure in the closed channel produces forces pA and $p_1\ A_1$, in which p and p_1 are the intensities of pressure on the two faces. The resultant of these four forces (and also of the weight of the water contained in the space) must be balanced by the reaction exerted by the walls of the containing vessel, including friction and direct pressure.

In the case of the Pitot tube, about to be discussed, a small section of the stream in the form of a cylinder surrounding the axis of the Pitot tube will be treated in the light of the principles above outlined. In this case it should be kept in mind that the tube is supposed to be placed in the midst of a stream of indefinite extent in all directions, moving with uniform velocity, and that the walls of the pipe surrounding the water shown in Fig. 2 and the tank of Fig. 1 are now replaced by the Pitot tube, which is the only stationary part which can receive the reaction of the water. There is no other fixed piece which can create either frictional or dynamic resistance to the stream, so that the tube must be subjected to the entire reaction corresponding to the deflection of the stream, unreduced by any frictional or other losses.

THEORY OF THE PITOT TUBE

The sketch, Fig. 3, represents a flat plate placed normally to the current in a large body of flowing water. The general character of the flow is indicated by the curved lines. Consider the water contained within the dotted cylinder shown. Starting at a point so far upstream that the effect of the plate is not

felt, the water entering the cylinder has the velocity V, which is the velocity of the entire stream relatively to the plate. The water exerts against the water contained within the imaginary cylinder the impulse

$$\frac{w\,AV^2}{g}$$

in which w is the specific weight of the water and A is the transverse area of the cylinder. In an old theory of the Pitot tube it was assumed that this force was entirely balanced by the pressure of the plate exerted against the right hand end of the cylinder, so that the intensity of this pressure would be

$$p = \frac{\frac{w\,AV^2}{g}}{A}$$

which corresponds to a static head of

$$h = \frac{p}{w} = \frac{V^2}{g}$$

This assumption, however, took no account of the fact that the water not only enters the cylinder, but also has to get out again, which it does by discharging at varying angles of obliquity along the sides of the cylinder. The backward reaction of the outgoing water will of course greatly reduce the intensity of

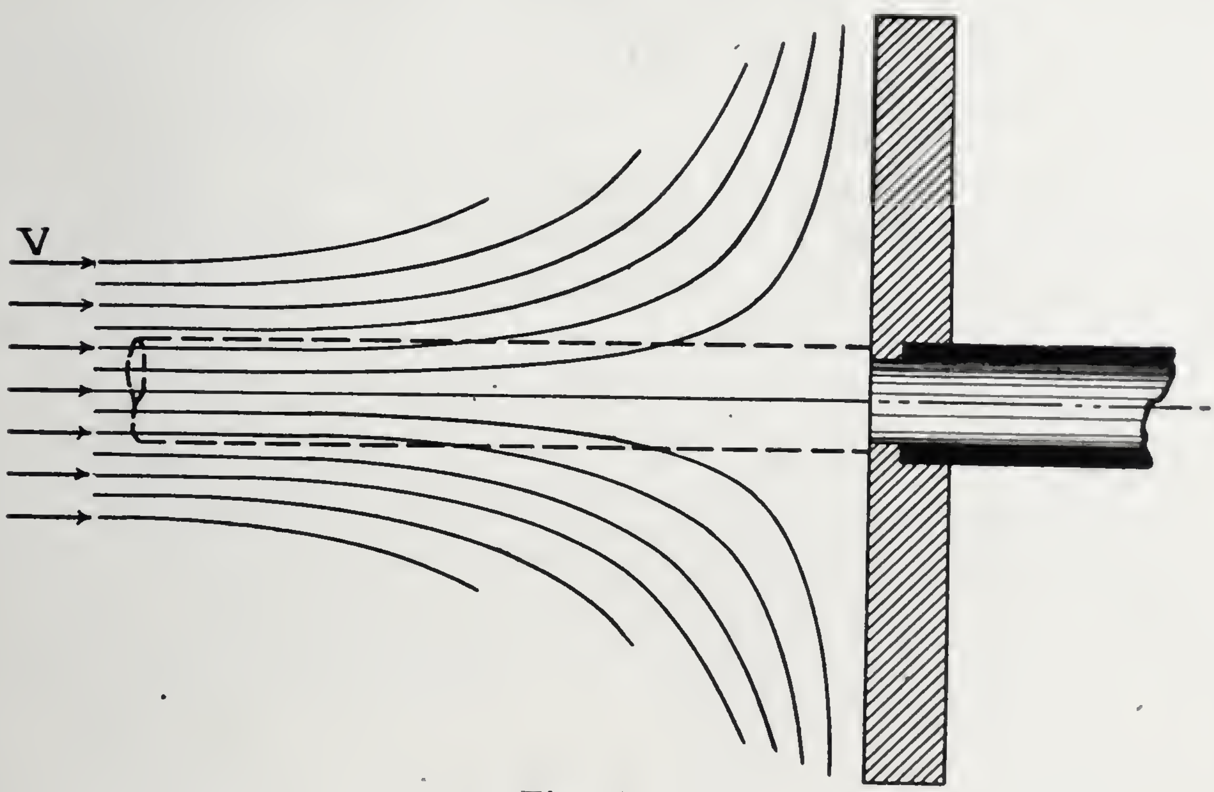


Fig. 3.

the pressure which must be exerted by the plate below that corresponding to a head of

$$\frac{V^2}{g}$$

Without assuming "stream-line flow", or flow without frictional resistance or energy loss, or any other hypotheses at variance with ordinary conditions, let us investigate the forces acting in the above described imaginary cylinder, with the aid of the following artifice:

From the necessarily diverging character of flow sketched above, it must be possible to subdivide the cylinder into an in-

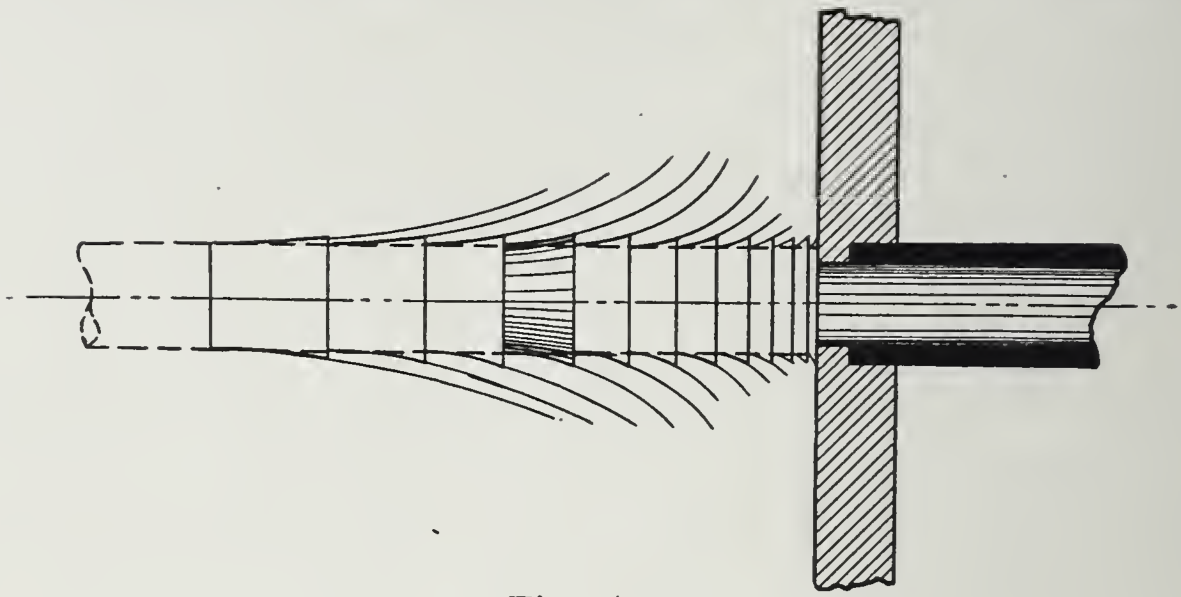


Fig. 4.

definite number of small sections, each bounded by two planes normal to the axis of the cylinder and a surface of revolution enlarging toward the downstream side, the enlargement in area being made sufficient to permit the same quantity q which enters the upstream face to be discharged across the downstream face. The cylinder is thus seen to be made up of an indefinite number of such sections (Fig. 4), which when increased to an infinite number, will form a smooth cylinder.

Consider any one of these elementary sections (Fig. 5): If the upstream face of every elementary section has the same area A, the weight of water entering one of these elements will be $W = wAv$, v being the velocity at the upstream face. The impulse, acting toward the right, of the entering water will then be

$$\frac{Wv}{g}$$

and the reaction, acting toward the left, of the water leaving the downstream face will be

$$\frac{Wv_1}{g}$$

v_1 being the velocity at the downstream face. Since no water enters or leaves the lateral bounding surface, W will be the same in both expressions and the difference of these forces will represent the axial thrust exerted, or

$$dF = \frac{W}{g}(v - v_1) = \frac{wAv}{g}(v - v_1).$$

As the number of elements is indefinitely increased, the two faces of any element can be drawn closer and closer together,

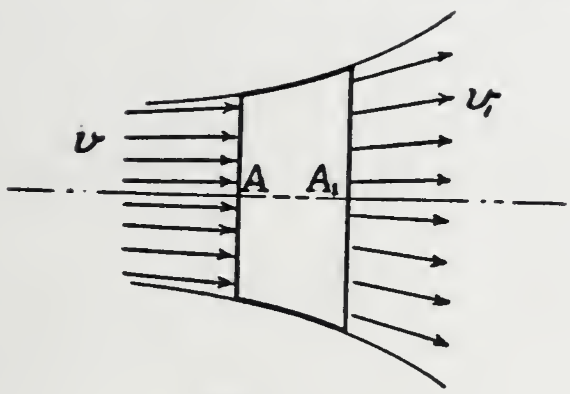


Fig. 5.

until the areas of the two faces differ by a differential amount and the difference of the two velocities $v - v_1$, becomes equal to $-dv$, (the minus sign being used because v is decreasing). Then

$$dF = -\frac{wAv}{g}dv$$

The integration of the last expression over the whole length of the cylinder will give us the total force which must be balanced by pressure at the surface of the plate. The velocity, which is V at the upstream end of the cylinder, continually diminishes as more and more water is discharged through the cylinder walls, until at the plate all velocity in the axial direction disappears. The limits of integration are therefore

$$v = V \text{ and } v = 0; \text{ and}$$

$$F = -\int_V^0 \frac{wAv}{g}dv = \frac{wA}{g}\frac{V^2}{2}$$

Since A is constant throughout the length of the cylinder.

The intensity of pressure on the plate is therefore

$$p = \frac{F}{A} = \frac{wV^2}{2g} \quad {}^1$$

EXPERIMENTAL VERIFICATION OF THEORY

Under conditions of very smooth flow, free from eddies and turbulence, the above result applies directly and gives very precise results, as has been experimentally proven many times. See "The Pitot Tube, Its Formula", by W. M. White[2], and "The Frictionless Orifice", by Judd & King[3].

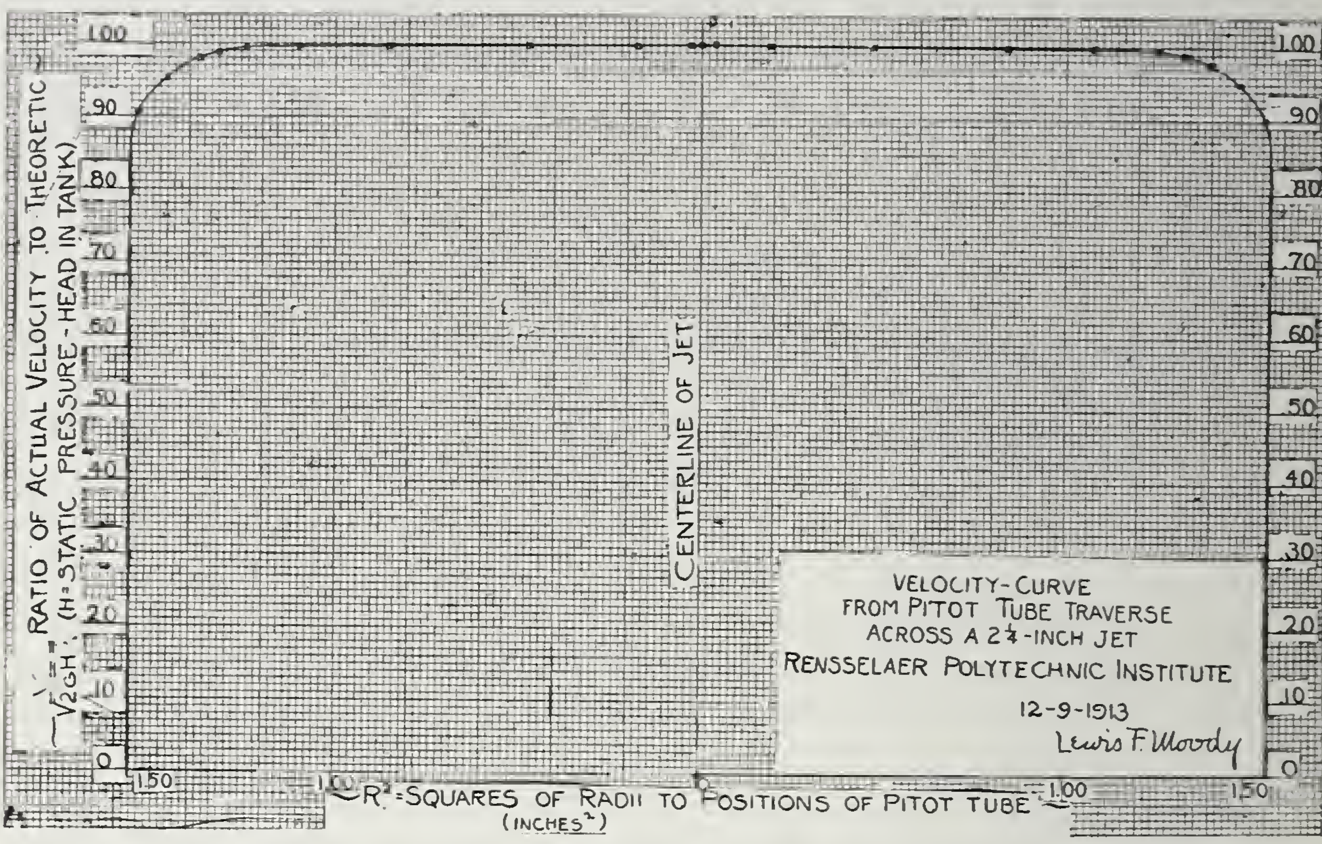


Fig. 6.

Some tests made by the writer at the Sage Laboratory, Rensselaer Polytechnic Institute, may be described in this connection.

A tank 2 ft. 6 in. diam. by 4 ft. 0 in. long, into which water could be run through a 6-inch pipe at one end, was fitted at the other end with a tapering head and nozzle, which reduced the area of stream gradually until a 2½ in. diam. jet was discharged into the air. The velocity-head in the tank was negligibly small. A pair of small Pitot tubes made of fine copper tubing were moved across two perpendicular diameters of the jet, and the readings compared with the static pressure in the

[1] A method similar to the above for deducing the Pitot tube formula was suggested by Mr. F. H. Rogers, Asst. Hyd. Engr., I. P. Morris Co.

[2] Jour. Assn. Engrg. Soc. 1901, v. 27, p. 35.

[3] Engrg. News, 1906, v. 56, p. 326.

tank. Fig. 6 shows the result of these traverses. Up to within approximately $\frac{1}{4}$ in. of the surface of the jet, the Pitot tube indicated that the velocity throughout the central portion of the jet was exactly equal to the full theoretic velocity corresponding to the head producing the flow. Except for the effect of pipe—and air—friction in reducing the velocities near the periphery of the jet, the nozzle gave a perfect conversion of pressure head into velocity head, or of potential into kinetic energy; and the tube reconverted velocity head into static pressure without loss. A view of the gage board during this experiment is more convincing than a description, as it shows three gage glasses, connected to the two Pitot tubes and to the static peizometer of the tank, with the water columns standing at exactly the same elevation in each. Results such as this can be obtained only when the flow is free from turbulence, as is indicated in this experiment by the smooth transparent appearance of the jet.

Further verification of the Pitot tube formula will be found in the still-water tank tests which are described later.

EFFECT OF TURBULENT FLOW

When a stream whose current is to be measured contains a considerable amount of turbulence, as is usually the case in engineering practice when water is flowing in pipes or open channels at ordinary velocities, the effects of such turbulence on the readings of velocity-measuring devices must be considered. It is well known that at velocities usually employed in engineering work, the water flowing in a pipe or channel does not move in smooth stream lines, nor does the velocity at any given point remain constant either in direction or magnitude. A flowing mass of water is full of local whirls or vortices, and the stream at any point is subject to pulsations. At low velocities, or in small pipes, it is known that smooth stream-line flow may exist, but under usual conditions, the "critical velocity" is greatly exceeded, and the mode of flow just described is encountered.

In addition to the local disturbances of a transient nature above described there will also be in many channels a permanent state of distorted flow, due to irregularities of the chan-

nel; and this may give rise to persistent lateral velocities or oblique currents at a section of measurement.

As an example of the sort of flow which is sometimes met with, Fig. 7 is given, showing the variation in velocity across a

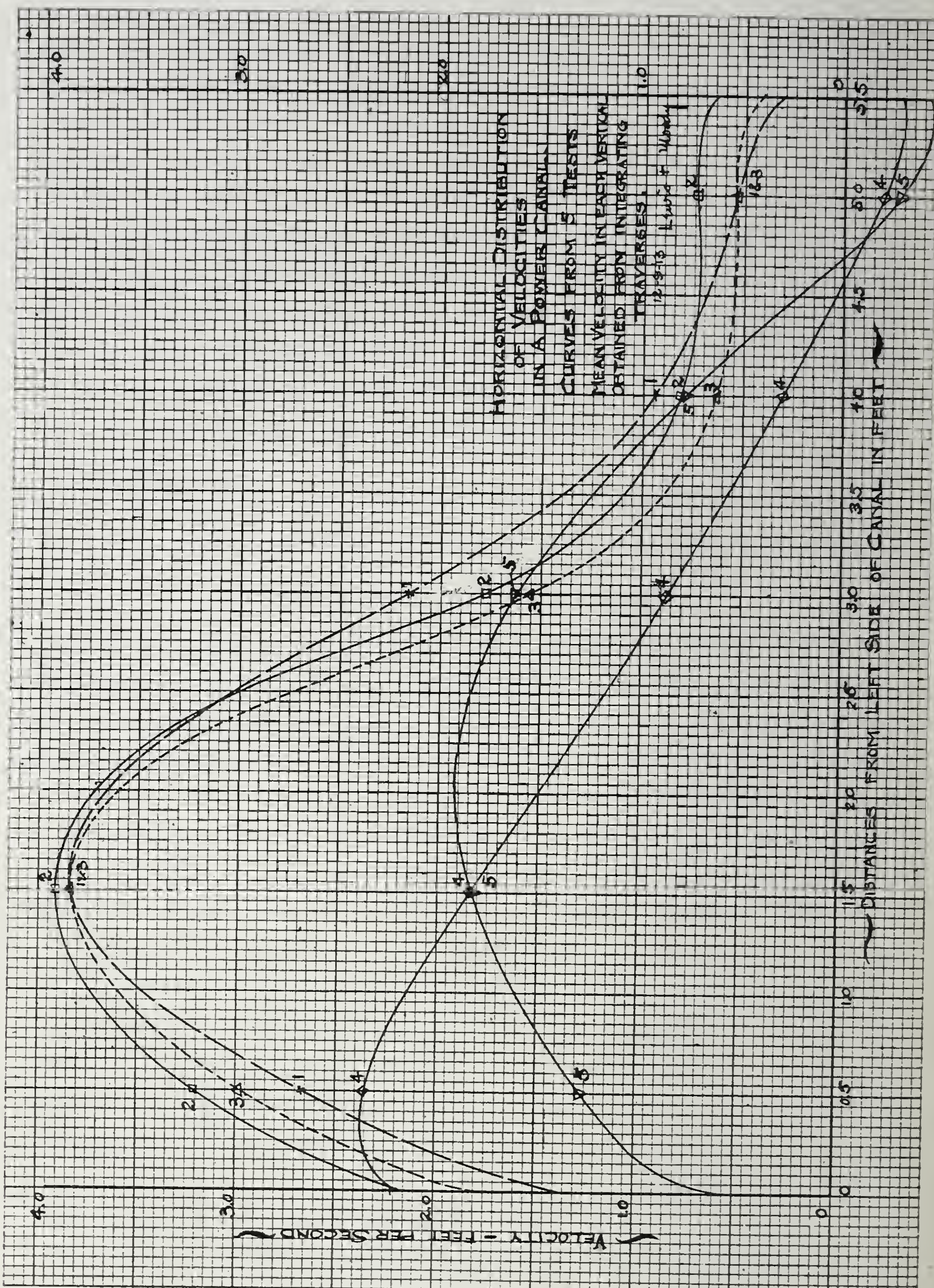


Fig. 7.

flume supplying a turbine in a mill. The flume was covered and was inaccessible except at the section of measurement. A sluice in the canal above this point gave the water a "set" toward the left side; and at some degrees of opening of the sluice gate this effect was so extreme that backward velocities occurred at the right-hand wall of the flume, as shown by traverses No. 4 and No. 5. The velocities were measured with a screw type of current meter. A meter of the cup type would have indicated positive velocities at all points, and would have given entirely misleading results.

Disturbed or irregular conditions of flow of the kinds described, affect the readings of both Pitot tubes and current meters. The effect on current meters has already been investigated by Mr. Groat, as explained in the paper referred to above; and tests to be described below have been made on both current meters and Pitot tubes.

The influence of turbulence on the readings of the Pitot tube can be separated into two effects: First, the variation of velocity from instant to instant causes a variation of the pressure on the tube, accompanied by an oscillation of the water column filling the tube and its connections; and although the variation of the water level in the glass of the gauge can be reduced by throttling the connecting tube, and by using a gauge glass larger than the orifice of the Pitot tube, nevertheless the tube will not give the exact head corresponding to the average velocity over an interval of time. The best the tube can do is to indicate the *mean head*, which corresponds to the *mean square* of the velocity; and this must theoretically always be in excess of the head corresponding to the mean velocity.

The second effect is the variation in the direction of the velocity due to eddies and lateral pulsations perpendicular to the flow. The result of this is to make the water impinge on the point of the Pitot tube at various angles instead of perpendicularly.

The two effects were investigated by the following methods: First, the Pitot tube (or current meter) was mounted on a car traveling on a track above a rating tank in which the water was still, the car being moved uniformly and the tube placed in line with the direction of motion. An oscillating motion was

then given the tube, the oscillations being parallel to the direction of motion of the car. The tube (or meter) was then turned at various angles to the motion and moved with uniform velocity, without oscillation. The first method varied the value of the pressure acting on the tube without changing the direction of the velocity relatively to the tube, and therefore indicated the error caused by variation of the pressure from the mean. The second method showed the effect of oblique impact on the tube.

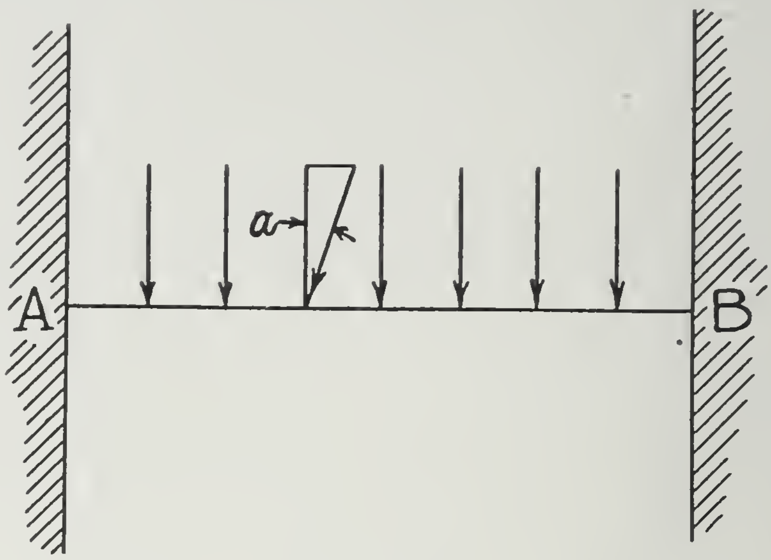


Fig. 8.

Two additional methods were applied. These combined both of the above described effects, in an attempt to simulate conditions encountered in the natural flow in pipes and channels. One series of tests consisted in moving the tube in the direction of its own axis with uniform velocity, and giving it at the same time transverse oscillations perpendicular to the

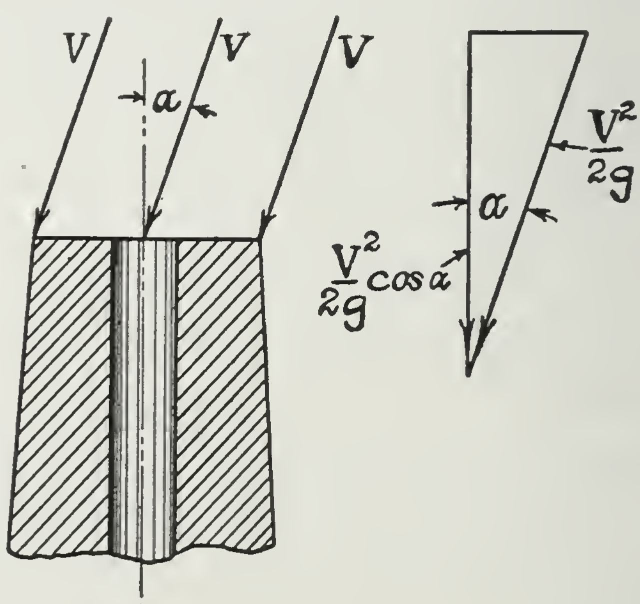


Fig. 9.

first motion. These tests gave the combined effects of variation of pressure and of direction of flow. The remaining method consisted in moving the instrument uniformly in its proper direction through water artificially disturbed.

The latter test was applied to the current meter, the water being disturbed in advance of the car by the somewhat crude expedient of stirring it up with a broom. Without giving the details of this experiment, it may be said that it served to corroborate the results obtained by Mr. Groat on similar types of current meters. This method was not applied to the Pitot tube.

In order to study more carefully the effect of oblique flow or lateral components of velocity at a section of a channel used for discharge measurements, the following theoretic considerations are given:

In Fig. 8, *AB* represents a section normal to a stream at which velocity measurements are to be made in order to determine the discharge. If the velocities at each point of measurement are normal to the section the discharge is simply

$$Q = \Sigma\ v \times \Delta A,$$

in which ΔA is the area of an element of the section. If, however, at any point the velocity at the instant of measurement is inclined to the normal at the angle α, then the elementary area should be multiplied by $v \cos \alpha$, the component of the velocity normal to the plane of the section, and

$$Q = \Sigma\ v \cos \alpha \times \Delta A.$$

If a Pitot tube or current meter could be made to read the component of velocity parallel to its axis, very little error would result from turbulence in a stream. It can be shown, however, that for small or moderate angles of inclination, the tube reads too high.

Consider, for instance, a flat-faced tube similar to that shown in Fig. 9. The pressure corresponding to the velocity V would be equivalent to a head of

$$h = \frac{V^2}{2g}$$

this pressure is exerted obliquely on the tube, and only its component $h \cos \alpha$ is applied normally to the face of the tube. The

perpendicular velocity which would give the same pressure would be

$$V_\epsilon = \sqrt{2g \times h \cos a} = V \sqrt{\cos a}$$

which is the equivalent normal velocity, and is the velocity which would be obtained from the head recorded by the tube. Therefore, instead of indicating a velocity of $V \cos a$, the tube gives us $V \sqrt{\cos a}$, which is always too high.

In order to test any Pitot tube, or current meter, in regard to the errors caused by turbulence, the writer uses the following method of working up the results: A curve is plotted between angles of inclination as abscissas and the ratio of indicated velocities to actual velocities as ordinates. A curve having ordinates equal to the cosine of the angle is also plotted; and the discrepancy between the two curves is taken as a measure of the error which will be caused by different degrees of turbulence. A curve giving the ratio of the ordinates of the two curves indicates the correction coefficient which should be applied.

STILL-WATER TESTS OF PITOT TUBES

The methods of investigation outlined above were applied in a series of experiments made in the fall of 1910 for the I. P. Morris Company of Philadelphia. The tests were conducted under the writer's direction by Mr. Frank H. Rogers, now Asst. Hydraulic Engineer of that company, and have been previously described in a thesis for professional degree submitted by Mr. Rogers to the University of Pennsylvania. The work was carried out in a most careful manner and the results are believed to be reliable.

DESCRIPTION OF APPARATUS AND METHODS OF TESTING

The rating flume and accessories are a part of the hydraulic equipment of the Russell Sage Laboratories, Rensselaer Polytechnic Institute, and were installed through the liberality of the firm of W. & L. E. Gurley, Troy, N. Y. The flume and equipment were designed under the direction of Prof. A. M. Greene, Jr.

The installation was intended primarily for the rating of current meters, but can be used for other lines of hydraulic

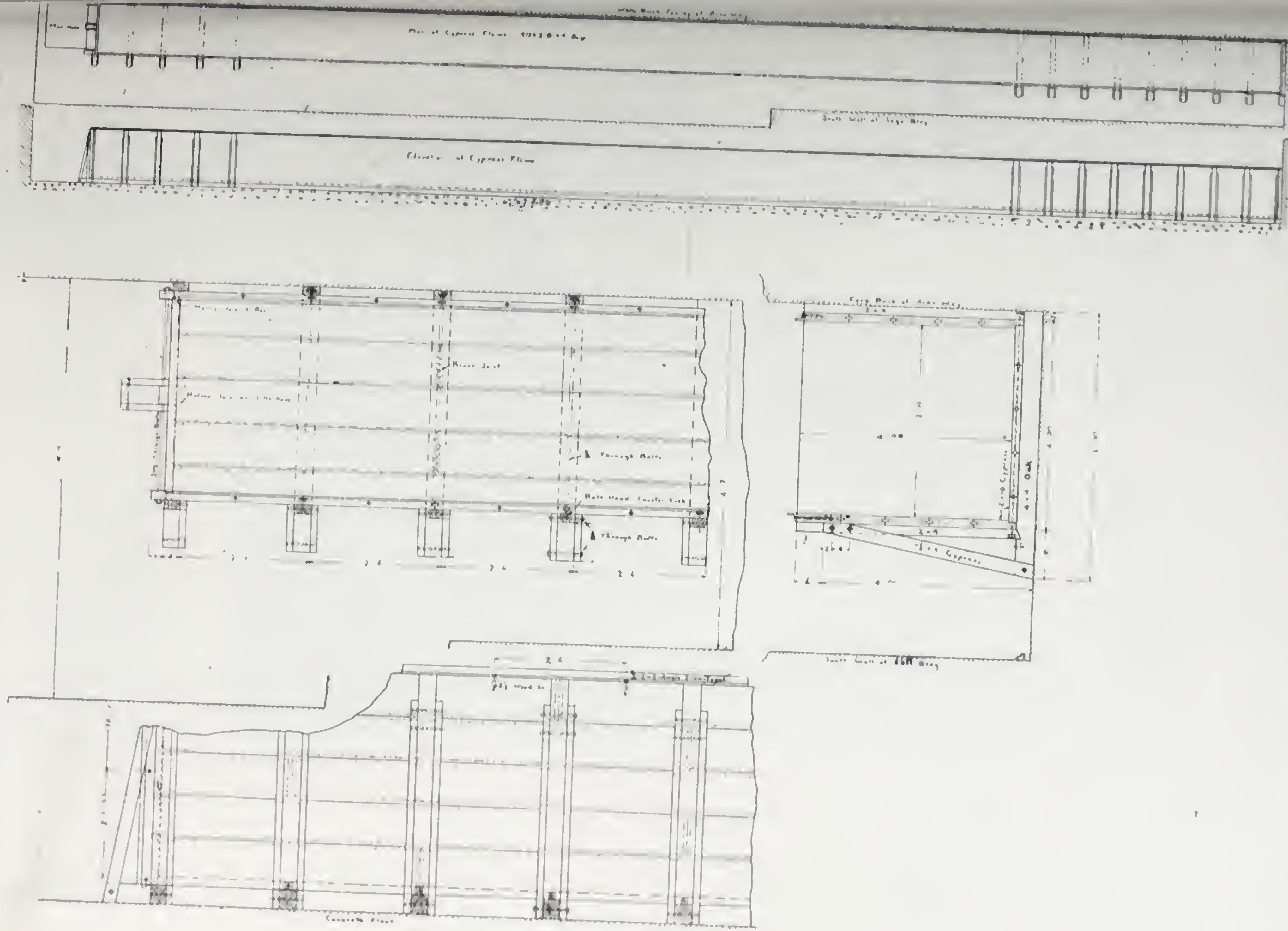
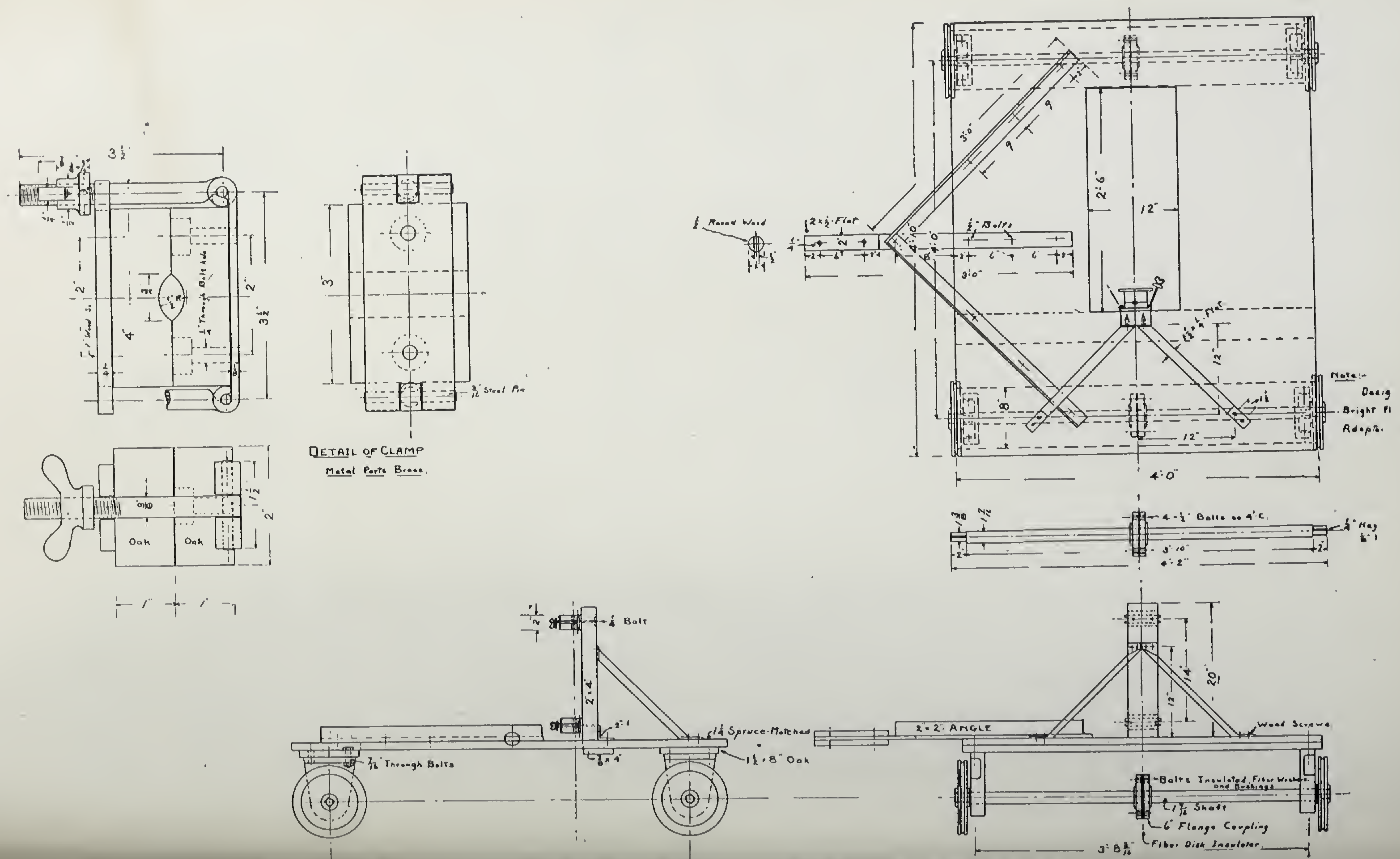


Fig. 10.



DETAIL OF CLAMP
Metal Parts Brass.
Oak
Oak
Steel Pin
Round Wood
Flat
Bolts
4'0"
3'0"
2'6"
12"
Note:-
4 - ½" Bolts on 4" C.
3'10"
4'2"
Key
Bolt
2"×4"
Spruce Matched
Oak
Through Bolts
2×2 ANGLE
Wood Screws
Bolts Insulated, Fiber Washers and Bushings
Shaft
6" Flange Coupling
Fiber Disk Insulator

research. The flume consists of a wooden tank 90 ft. 0 in. long by 3 ft. 8 in. wide by 4 ft. 0 in. deep (inside dimensions), a drawing of which is shown in Fig. 10.

The side walls of the tank are capped with tracks, placed truly level, on which runs a car or carriage which may be pushed by hand. This is shown in Fig. 11. A walk or runway is provided alongside the tank, at a convenient height for the pusher.

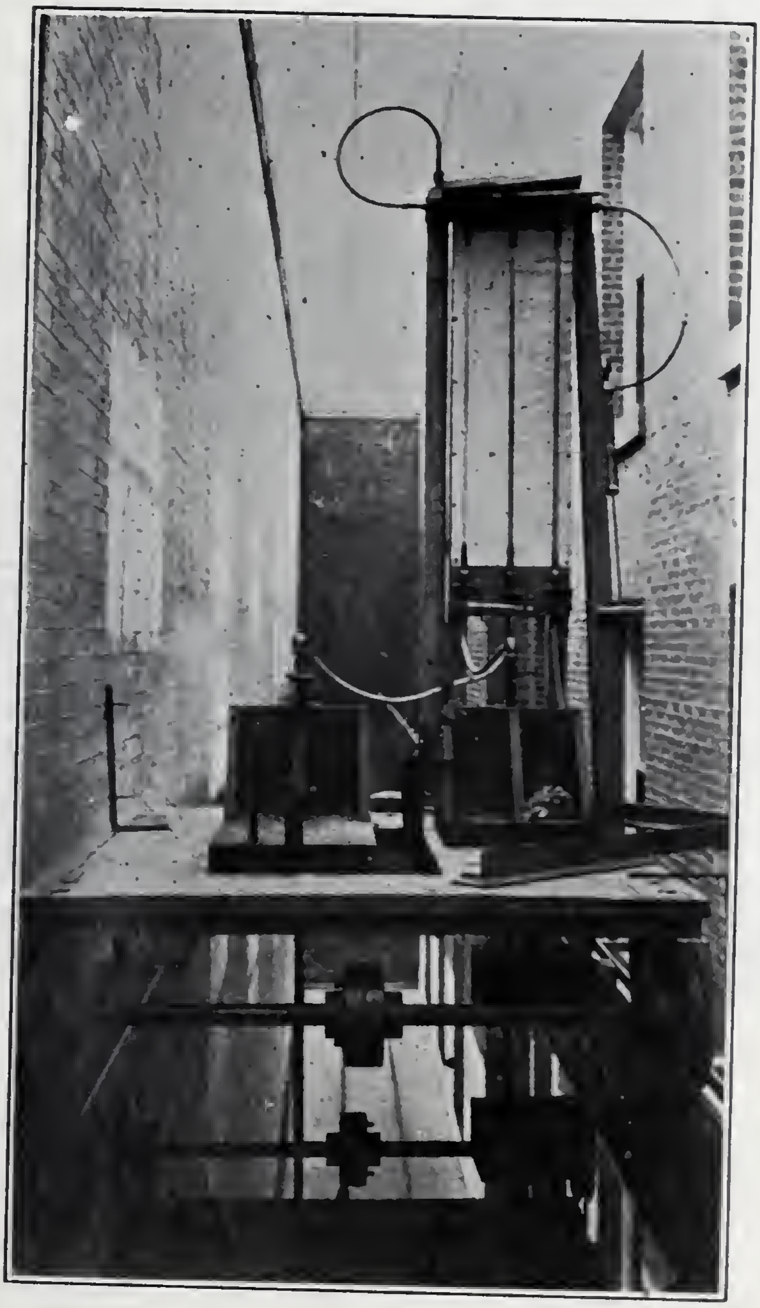


Fig. 12.

At present the car is equipped with a tachometer attached to the front axle, by means of which the pusher can maintain constant speed; but during the tests described, the speed was regulated by observation of a "standard" Pitot tube mounted on the car.

In these tests, the following apparatus was added to the

car: a gauge board, a small portable water tank attached to the car, a support for the standard Pitot tube, and a second support for the tube being tested. Two kinds of support were used for this tube: First, a device by which the tube could be turned at different angles, the angle being indicated on a scale; and second, a device for moving the tube with a reciprocating motion, consisting of a sliding support actuated by a heavy flywheel and connecting-rod. The flywheel could be turned by hand. Figs. 12 and 13 show the car arranged for testing a tube at various angles; Fig. 13 giving a good idea of the flume; and Figs. 14 & 15 show the arrangement for the oscillation tests.

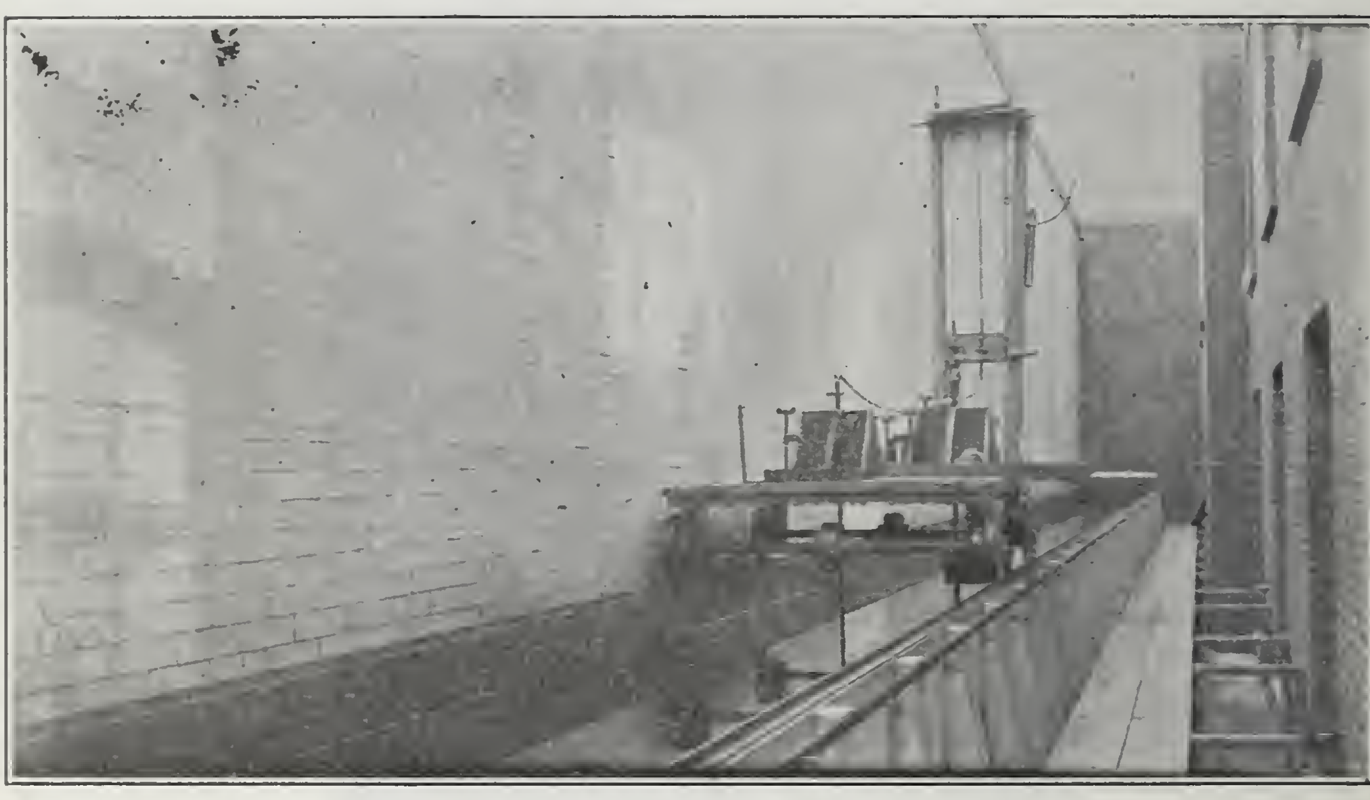


Fig. 13.

The flume is regularly equipped with a chronograph, shown in Fig. 16, which contains a drum carrying a chart, the drum being driven uniformly by clockwork, and three recording pens. These pens are actuated by magnet coils electrically connected respectively to: (*1*) a set of contact plugs spaced at known intervals along the tank so that the motion of the car is recorded; (*2*) the current meter under test, giving the number of revolutions of the meter; and (*3*) a standard clock ticking (in these tests) half-seconds. In this series of tests, the second pen, intended for current meters, was disconnected. Typical chronograph records, obtained on two current meter ratings, are shown in

Fig. 17. The upper line of each set of three shows ticks of the clock; the middle line, marks corresponding to eight-foot spaces traveled by the car and the lower line, revolutions of the meter. The electrical connections to the car are made through two trolley wires, which can be seen in Fig. 13.

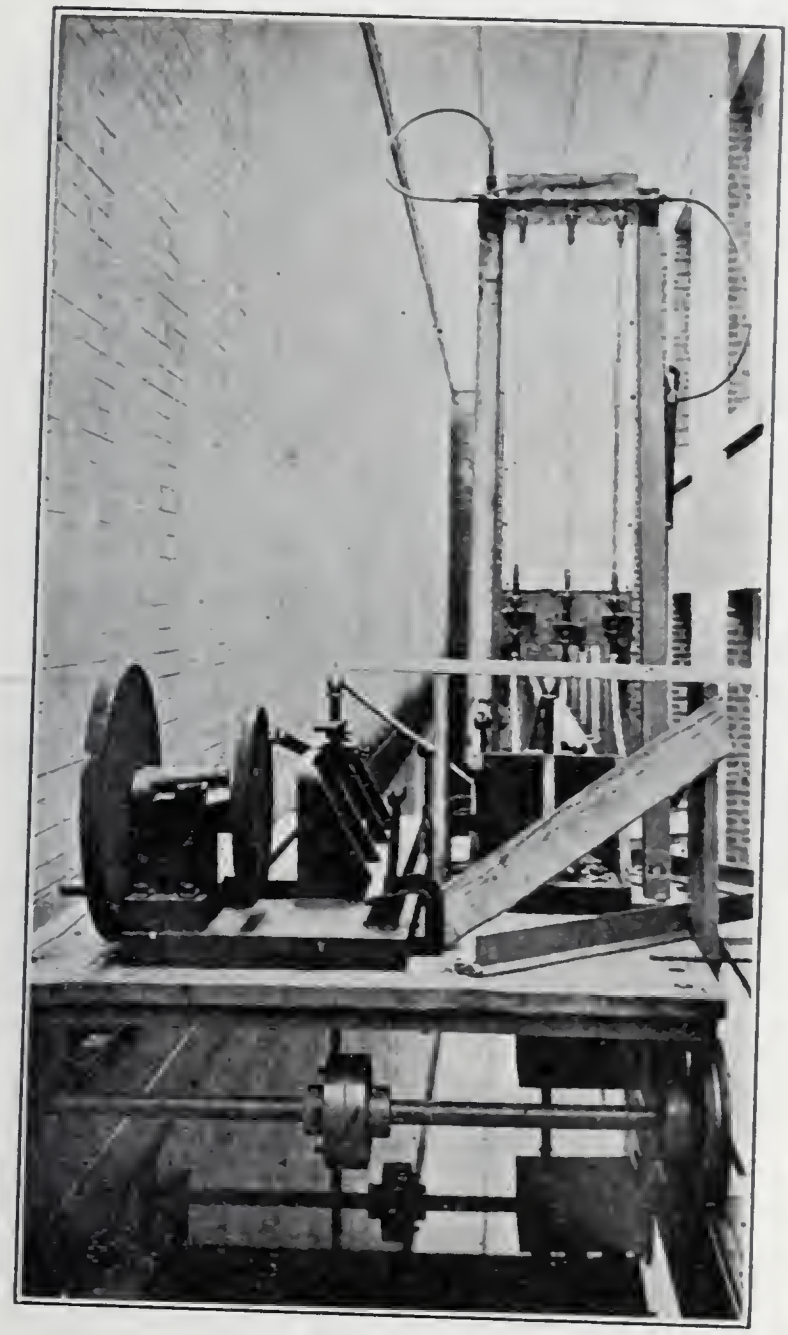


Fig. 14.

In addition to determining the absolute value of the speed of the car by means of the chronograph, a Pitot tube held stationary with respect to the car, and with its axis in the line of motion, was used as a standard, as already mentioned. The readings of the various tubes under test were then taken simultaneously with the standard tube, so that accurate comparative results could be obtained.

In order to bring the gauge columns to a convenient height for reading, the gauge tubes were connected to a common header

at the top of the board, and this communicated with a large pipe used as a vacuum tank. The air was exhausted in this tank until a sufficiently low pressure was obtained to draw the water columns to the middle of the board, the static pressure being recorded by a static tube connecting to the small water tank carried by the car. The mean elevation of the water surface in

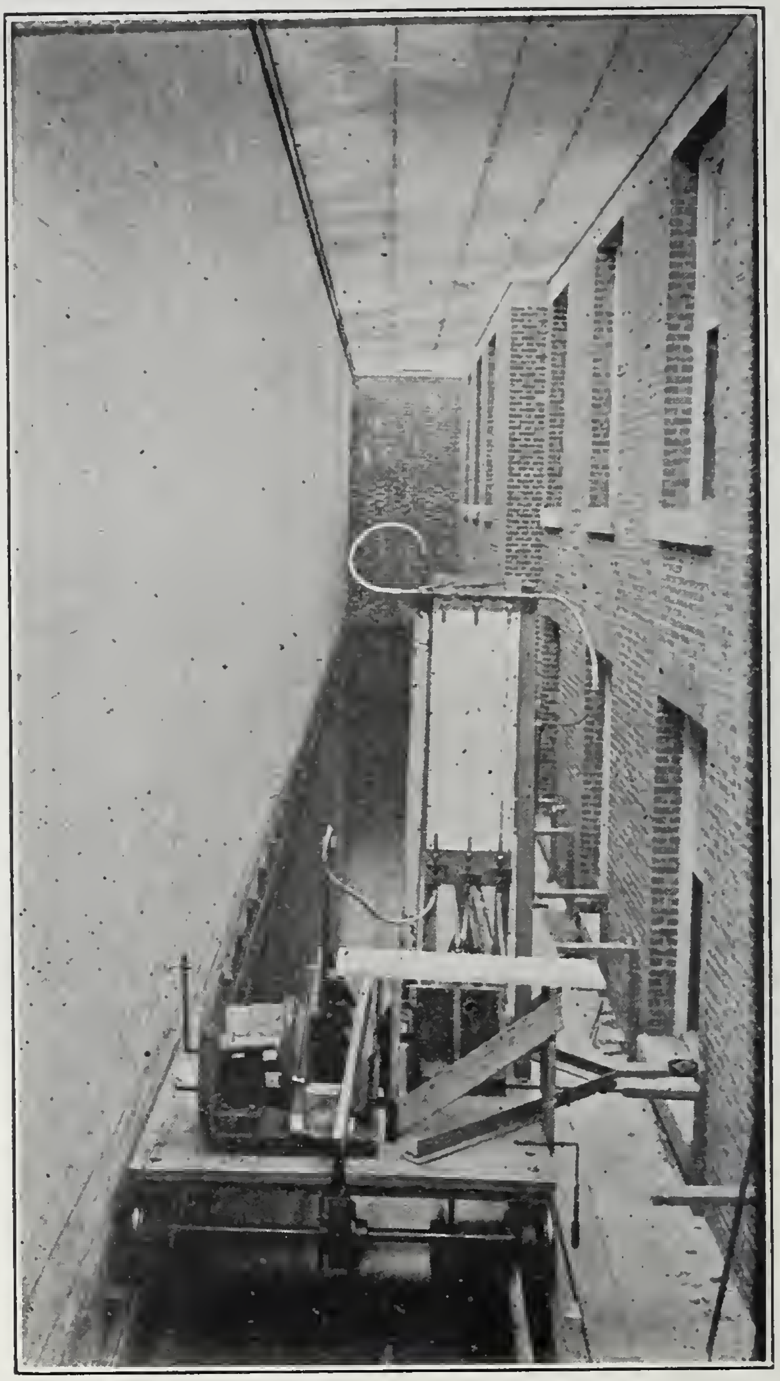


Fig. 15.

the small tank above that in the flume was accurately determined by placing the car at different positions along the tank and reading the gauge board with the car at rest.

The only point at which the apparatus did not prove to be entirely satisfactory was in the length of the flume. The length is found to be sufficient for current meter rating; but with Pitot

tubes it was necessary to obtain the average of a number of readings of the fluctuating water columns. In order to overcome difficulties due to the limited length of run, a brake was fitted to the car so that it could be run at full speed nearly to the end of the flume and quickly stopped; and a number of observers and recorders were used on the car to enable readings to be taken rapidly. In some of the tests as many as five men were placed on the car, a sixth man being required as pusher. Fig. 18 shows the arrangement of the experimenters on the car. After some practice a considerable amount of skill was developed in bringing the gauge columns quickly to their

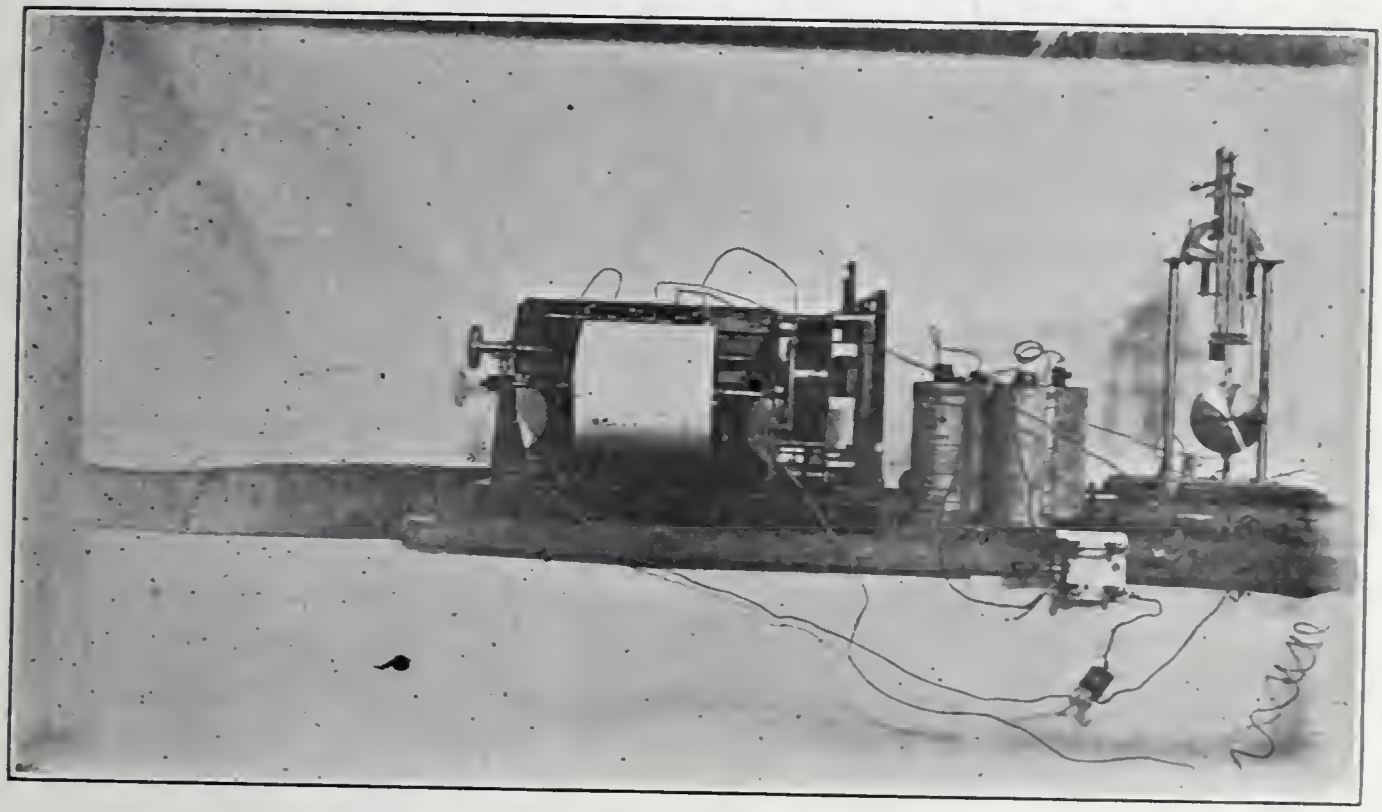


Fig. 16.

proper reading and then keeping the velocity of the car uniform to avoid vibrations of the water columns. These measures permitted satisfactory results to be obtained from all experiments in which the Pitot tubes were held stationary relatively to the car; but in the tests made with oscillating tubes, many of the runs were unreliable on account of lack of time for the gauge columns to rise to their proper elevations, and insufficient time to obtain enough readings of the fluctuating pressures to give a reliable average.

RESULTS OF TESTS

As explained above, the exact speed of the car for any one run could be more accurately obtained from a standard Pitot

tube than from the actual distance and time of car movement. The comparison of a tube under test with the standard tube could thus be made with the two tubes subjected to exactly the same conditions. During these comparative tests however, the speed of the car as recorded by chronograph was also taken for each run, and the data thus collected furnished an excellent still-water rating of the standard tube. The runs from which the rating was made were thus the same runs as those used for the comparative tests, so that the numbers of runs appear twice in the following tables. Runs 1 to 37 were preliminary and were not used.

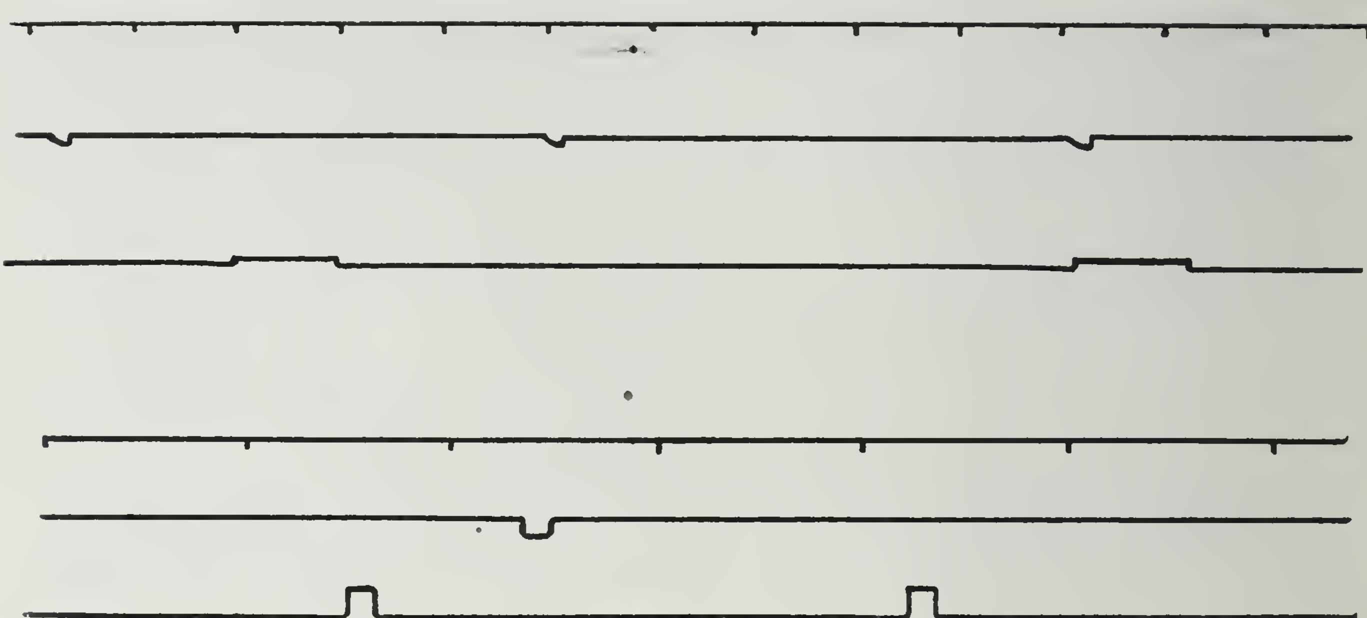


Fig. 17.

Table No. 1, gives the data on which this rating was based, and is self-explanatory. The average value of the tube coefficient k in the formula: true velocity $= k \sqrt{2gH}$, or the ratio of the velocity of the car to the velocity indicated by the tube, was 0.9983. This value differed from unity by an amount less than the probable error computed from the readings themselves. It is also believed by the writer that there may have been a slight error in the measurement of the scale divisions on the gage board; since at a date subsequent to the test a rechecking of the gage scale showed a shrinkage of $\frac{1}{16}$ in. in 4 ft. which would raise the coefficient to approximately 0.9990. The latter correction is immaterial, however, since there were practically as many values of the coefficient above unity as below; and as far as the evidence of the test goes, the value of the coefficient was as likely to have been unity as not. The

velocities ranged between 4.74 and 7.813 feet per second; and no systematic variation of the constant of the tube was shown.

For the remainder of the tests, the coefficient of the standard tube was taken as unity.

Fig. 18.

The standard tube will be referred to as tube "A". In addition to "A", five other Pitot tubes of various forms were tested. These are shown in Fig. 19, arranged alphabetically starting from the left. Tube "A" has a moderately blunt end, faced off in a flat face. Tube "B" is similar to "A" but slightly larger in diameter. Tube "C" is a long tapering tube ending in a sharp edge. Tube "D" is funnel-shaped, "E" is similar to

"*A*" and "*B*" but larger in diameter of face; and "*F*" is a broad flat-faced tube forming practically a flat plate held normal to the stream. The dimensions of the tubes are given in Figs. 21 to 25, and also in Fig. 20.

TABLE NO. 1.

CALIBRATION OF STANDARD PITOT TUBE "A" BY COMPARISON WITH VELOCITY OF CAR.

Test	Date	Veloc. by Pitot Tube Ft. per Sec. V	Distance Traversed by Car in Ft. D	Time in Seconds by Chronograph T	Time Correction Factor F	Veloc. of Car $Vc = \frac{D}{T \times F}$	Tube Coefficient $K = \frac{Vc}{V}$	REMARKS
38	9/24/10	3.153	40	11.10	1.00662	3.577	1.134	In Tests 38-41 Inc. All
39	"	2.90	64	19.00	"	3.341	1.152	Gauges Read by One
40	"	3.283	56	15.40	"	3.610	1.103	Observer so Results Not
41	"	3.718	56	14.00	"	3.971	1.066	Accurate
42	"	4.440	48	10.70	"	4.452	1.0025	Therefore Omit These
43	"	4.36	56	12.50	"	4.397	1.0100	Tests in Average
44	"	4.33	64	14.35	"	4.426	1.0215	
45	"	4.624	56	12.00	"	4.627	1.0010	In Remaining Tests
46	"	4.680	56	11.80	"	4.705	1.0050	All Gauges Were Read
47	"	4.828	56	11.25	"	4.892	1.0140	Simultaneously
48	"	5.685	56	9.90	"	5.620	0.9900	
49	"	5.995	56	9.30	"	5.978	0.9978	
50	"	6.140	48	7.80	"	6.118	0.9960	For Tests 38-52
51	"	6.120	40	6.50	"	6.118	0.9990	Chronograph Clock
52	"	6.310	40	6.35	"	6.258	0.9920	Was 2/5 Sec. Slow Per
53	"	5.437	Chron.	did not	Register	Time.		Min. Correct Time
54	"	5.366	40	7.55	1.00464	5.278	0.9836	= T × 1.00662
55	"	6.135	40	6.65	"	5.992	0.9767	
56	"	6.174	32	5.20	"	6.132	0.9932	After Test 52, Pendulum
57	"	6.590	40	6.05	"	6.563	0.9959	of Clock was Shortened,
58	"	7.086	40	5.70	"	6.986	0.9859	then Calibration Showed
59	"	6.961	48	6.90	"	6.932	0.9958	Clock was 1 2/5 sec's
60	"	6.716	32	4.70	"	6.77	1.0080	Slow for 5 Minutes
61	"	6.720	40	5.80	"	6.86	1.0208	then Correct Time =
62	"	6.795	40	5.00	"	6.808	1.0019	T × 1.00464
63	"	6.932	40	5.80	"	6.86	0.9896	
64	"	6.920	40	5.75	"	6.92	1.0000	This Time Factor the
65	"	6.738	40	5.90	"	6.75	1.0018	Same for all Remaining
66	"	6.852	40	5.70	"	6.968	1.0169	Tests
67	"	7.086	48	6.80	"	7.039	0.9934	
68	"	7.641	40	5.15	"	7.73	1.0117	For Tests 38-110.
69	"	7.815	24	3.10	"	7.715	0.9872	Depth of Tube Point Be-
70	"	6.741	40	5.90	"	6.75	1.0013	low Surface = 20″
71	"	7.865	40	5.10	"	7.813	0.9934	Distance of Tube from
72	"	6.718	48	7.20	"	6.640	0.9884	Side of Tank = 8⅞″
73	"	6.542	40	6.00	"	6.64	1.0150	Depth of Water in Tank
74	"	6.795	40	5.87	"	6.780	0.9978	= 40″
75	"	7.131	32	4.50	"	7.08	0.9929	
76	"	7.395	40	5.40	"	7.374	0.9972	
77	"	6.840	32	4.70	"	6.784	0.9918	
78	"	6.561	Chron.	did not	Register	Time.		
79	"	6.893	40	5.75	"	6.923	1.0043	
80	"	6.583	40	6.00	"	6.640	1.0087	
81	"	6.703	40	5.90	"	6.745	1.0063	
82	"	6.384	40	6.30	"	6.32	0.9900	
83	"	6.435	48	7.55	"	6.332	0.9840	
84	"	6.272	40	6.25	"	63.71	1.0158	
85	"	6.660	32	4.85	"	6.566	0.9859	
86	"	6.180	32	5.20	"	6.127	0.9914	
87	"	6.720	40	5.95	"	6.696	0.9964	
88	"	6.980	40	5.70	"	6.988	1.0015	
89	"	6.100	Chron.	did not	Register	Time.		

TABLE NO. 1—CONTINUED

Test	Date	Veloc. by Pitot Tube Ft. per Sec. V	Distance Traversed by Car in Ft. D	Time in Seconds by Chronograph T	Time Correction Factor F	Veloc. of Car $Vc = \frac{D}{T \times F}$	Tube Coefficient $K = \frac{Vc}{V}$	REMARKS
90	9/24/10	6.210	48	7.73	1.00464	6.186	0.9961	For Tests 198-275
91	"	6.395	40	6.25	"	6.372	0.9964	Depth of Tube Point Be-
92	"	6.490	32	4.85	"	6.565	1.0115	low Surface = 20½″
93	"	6.560	40	6.17	"	6.46	0.9848	Depth of Water in Tank
94	"	6.090	40	6.52	"	6.107	1.0028	= 41⅛″
95	"	6.195	32	5.20	"	6.126	0.9889	
96	"	6.320	32	5.00	"	6.375	1.0087	
97	"	6.320	48	7.60	"	6.290	0.9953	
98	"	6.140	40	6.45	"	6.172	1.0052	
99	"	5.820	40	6.80	"	5.856	1.0062	
100	"	5.730	48	8.25	"	5.793	1.0110	
101	"	5.920	40	6.75	"	5.900	0.9966	
102	"	6.010	40	6.70	"	5.942	0.9887	
103	"	5.682	40	6.95	"	5.724	1.0074	
104	"	5.915	40	6.80	"	5.860	0.9907	
105	"	5.920	32	5.45	"	5.842	0.9868	
106	"	5.850	40	6.85	"	5.808	0.9928	
107	"	6.460	32	4.95	"	6.440	0.9969	
108	"	6.042	40	6.62	"	6.017	0.9959	
109	"	5.638	40	7.10	"	5.610	0.9950	
110	"	5.880	32	5.37	"	5.927	1.0080	
198	"	6.145	40	6.50	"	6.120	0.9959	
199	"	5.980	40	6.60	"	6.028	1.0080	
200	"	6.114	40	6.55	"	6.080	0.9944	
201	"	6.050	32	5.25	"	6.061	1.0018	
202	9/27/10	6.305	40	6.32	"	6.300	0.9992	
203	"	6.680	40	6.00	"	6.638	0.9937	
204	"	Chronograph Clock Irregular.						
205	"	Clock Missed Registering.						
206	"	6.415	40	6.20	"	6.420	1.0008	
207	"	Seconds Irregular.						
208	"	6.490	40	6.15	"	6.478	0.9982	
209	"	6.530	40	6.13	"	6.496	0.9948	
210	"	Car Failed to Register.						
211	"	6.645	32	4.85	"	6.574	0.9893	
212	"	6.438	40	6.15	"	6.470	1.0050	
243	"	Car Speed Irregular.						
244	"	6.420	40	6.20	"	6.420	1.0000	
245	"	6.418	40	6.25	"	6.374	0.9932	
246	"	6.460	40	6.13	"	6.492	1.0050	
247	"	6.620	32	4.85	"	6.562	0.9912	
248	"	6.348	40	6.33	"	6.286	0.9902	
249	"	6.440	40	6.25	"	6.366	0.9885	
250	"	6.495	40	6.15	"	6.476	0.9971	
251	"	6.835	40	5.90	"	6.742	0.9864	
252	"	6.735	32	4.73	"	6.735	1.0000	
253	"	6.795	40	5.85	"	6.800	1.0007	
254	"	6.330	32	5.05	"	6.306	0.9962	
		Test 255-259 Chronograph Not Indicating Properly.						
260	"	6.150	40	6.40	"	6.220	1.0114	
261		Car Speed Irregular.						
262	"	6.458	40	6.20	"	6.421	0.9943	
263	"	6.440	40	6.25	"	6.375	0.9899	
264	"	6.240	40	6.40	"	6.222	0.9971	
265	"	6.355	40	6.30	"	6.320	0.9945	
266	"	6.282	40	6.33	"	6.291	1.0014	
267		Chronograph Failed to Indicate.						
268	"	6.265	40	6.37	"	6.252	0.9979	
272	"	5.005	40	8.00	"	4.979	0.9948	
273	"	4.977	40	8.00	"	4.979	1.0004	
274	"	4.902	40	8.05	"	4.947	1.0092	
275	"	4.780	40	8.40	"	4.741	0.9918	

AVERAGE VALUE OF TUBE COEFFICIENT FOR 99 TESTS K = .9983

Table No. 2 gives the tests of tube "*B*" inclined at various angles, compared with tube "*A*" held straight. In this table V indicates the true velocity as given by the standard tube in feet per second, V_1 the velocity indicated by tube "*B*" in feet per second—that is

$$V_1 = \sqrt{2g \times (\text{head indicated by B})}$$

V_B is the velocity indicated by "*B*" referred to V as unity, or

$$V_B = \frac{V_1}{V}$$

V_R is the resolved velocity, or the velocity which the tube should indicate to record the true discharge of a stream, again referred to V as unity, or

$$V_R = \frac{V \cos \theta}{V} = \cos \theta$$

Finally the ratio

$$\phi = \frac{V_R}{V_B}$$

is the correction factor, or tube coefficient, which must be applied to the reading to obtain the true value of the resolved velocity.

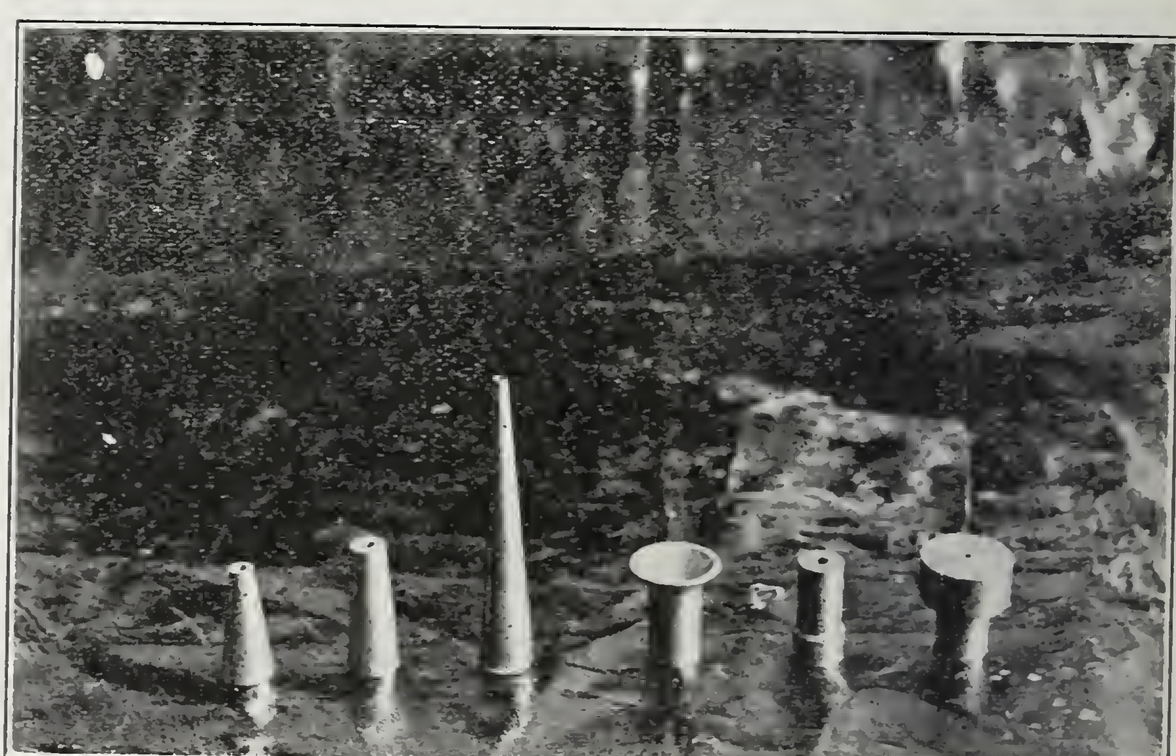


Fig. 19.

If by any means we can determine the average amount of obliquity of flow in a stream, the value of ϕ corresponding to

this angle would be the proper coefficient to apply to the velocities indicated by the tube in order to obtain the true discharge. This average obliquity of flow would be a function of the amount of turbulence in the stream, and a value might be obtained by noting the divergence in the indications of two tubes of different characteristics, or, in an open stream by using a current meter in addition to a Pitot tube.

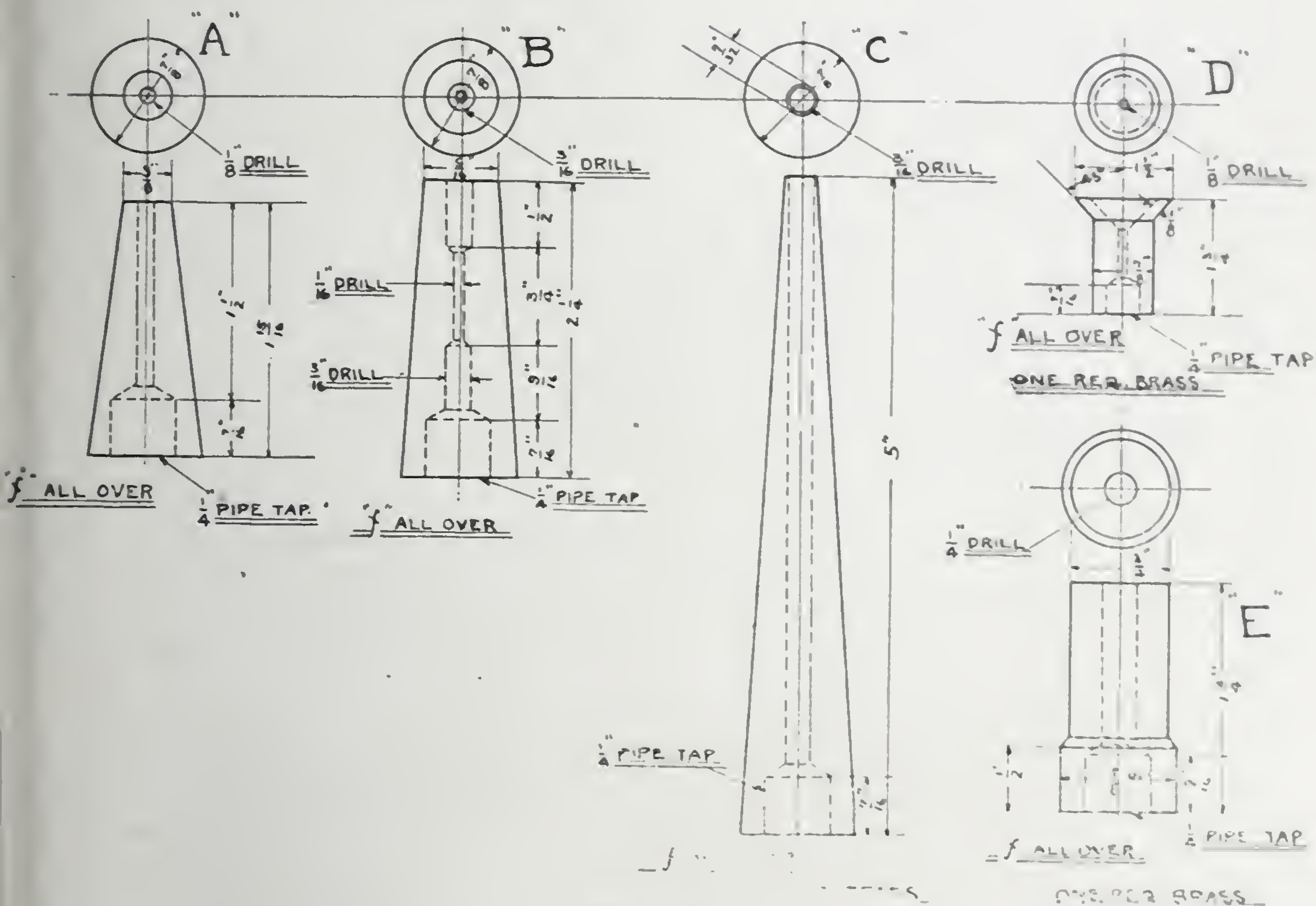


Fig. 20.

Tables Nos. 3, 4, 5, and 6 give the same data for tubes "*C*", "*D*", "*E*" and "*F*".

The results tabulated above are shown graphically in Figs. 21 to 25.

Referring to Fig. 21, which shows the results of the tests of tube "*B*", the values of V_B, the ratio of the velocity recorded by the tube to the true velocity, are plotted against the angles of inclination of the tube in the curve marked V_B. The velocities which the tube ought to record if it is to register the true discharge of a stream, are plotted in the curve marked $V_R = \cos\theta$. This curve is of course a sinusoid. The ratios of the ordinates of the cosine curve to those of the V_B curve are

the correction factors or tube coefficients to be used with this type of Pitot tube, and these are shown for various angles in the curve marked ϕ.

TABLE NO. 2.

PITOT TUBE "B" AT VARIOUS ANGLES COMPARED TO STANDARD TUBE "A"

DATE—9/24/10

Test	Angle of Tube "B" From 0° θ	Veloc. by Stand. Tube at 0° Ft. Per Sec. V	Veloc. by Tube "B" Ft. Per Sec. V_1	$V_B = \frac{V_1}{V}$	Average V_B	Resolved Veloc. $V_R = \frac{V \cos \theta}{V}$	Tube Coefficient $\phi = \frac{V_R}{V_B}$	REMARKS
69	0°	7.815	7.808	0.9991				Inside Width of Tank = 3′ — 8½″
70	0°	6.741	6.740	0.9999	0.9998	1.0000	1.0002	
71	0°	7.865	7.855	0.9987				
72	0°	6.718	6.725	1.0015				
66	5°	6.852	6.821	0.9955				Depth of Water in Tank = 40″
67	5°	7.086	7.107	1.0028	0.9979	0.9962	0.9983	
68	5°	7.641	7.606	0.9954				
62	10°	6.795	6.775	0.9971	0.9953	0.9848	0.9894	Depth of Tube Points Below Surface = 20″
63	10°	6.932	6.876	0.9919				
64	10°	6.920	6.866	0.9922				
65	10°	6.738	6.738	1.0000				
53	15°	5.437	5.392	0.9917				Dist. of Std. Tube from one side Tank = 8⅞″
54	15°	5.366	5.344	0.9959				
55	15°	6.135	6.090	0.9927	0.9906	0.9659	0.9751	
56	15°	6.174	6.119	0.9911				Dist. Tube "B" from other side Tank = 17¼″
57	15°	6.590	6.514	0.9885				
58	15°	7.086	7.000	0.9879				
59	15°	6.961	6.876	0.9878				Distance between Tubes = 18⅜″
60	15°	6.716	6.645	0.9894				
61	15°	6.720	6.655	0.9903				
73	20°	6.542	6.350	0.9708				The Gauges Connected to Tube "A", Tube "B", and the Pressure Box, were Read Simultaneously by Three Observers. All Angles Under θ are Measured to the Right from the Line of the Direction of Motion.
74	20°	6.795	6.600	0.9713	0.9694	0.9397	0.9694	
75	20°	7.131	6.917	0.9700				
76	20°	7.395	7.140	0.9655				
77	25°	6.840	5.960	0.8708				
78	25°	6.561	6.165	0.9397				
79	25°	6.893	6.462	0.9374	0.9376	0.9063	0.9666	
80	25°	6.583	6.160	0.9358				
81	30°	6.703	6.102	0.9105				
82	30°	6.384	5.820	0.9117	0.9113	0.8660	0.9503	
83	30°	6.435	5.860	0.9107				
84	30°	6.272	5.682	0.9123				

On theoretical grounds it was believed that the flat-faced tubes would record the velocities corresponding to resolved pressures instead of resolved velocities, as already explained and to test this theory the curve marked $V_T = \sqrt{\cos\theta}$ has been plotted. It will be noted that this tube gives exact agreement between the V_T and V_B values up to an inclination of 20 deg., and that the value of ϕ varies from unity at 0 deg. inclination to 0.95 at 30 deg. As angles of obliquity as great as this are not looked for in any ordinary stream, the inclination was not usually carried beyond 30 deg. in these tests.

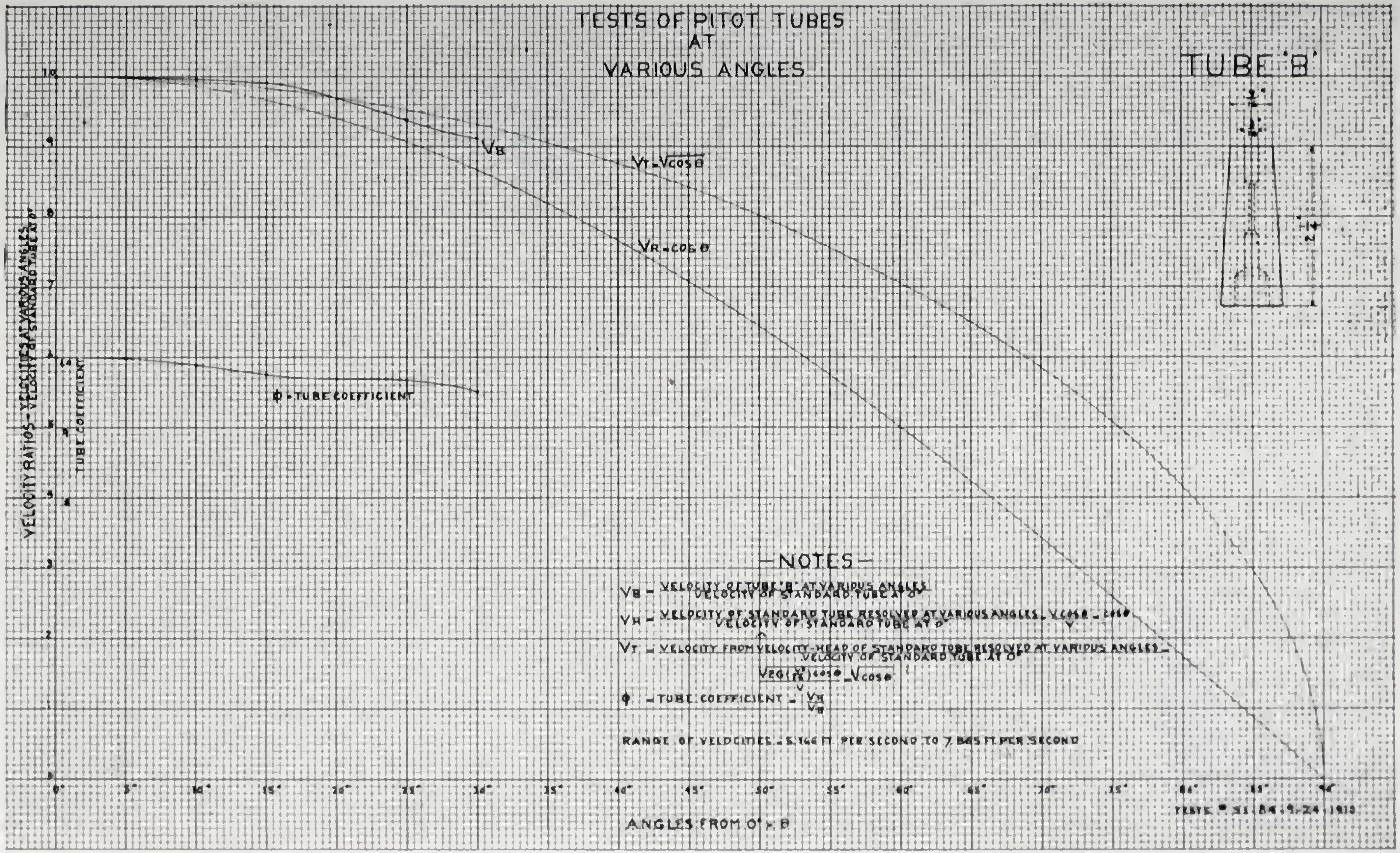

TESTS OF PITOT TUBES
AT
VARIOUS ANGLES
TUBE 'B'
VB
VT - √COS θ
VR - COS θ
φ - TUBE COEFFICIENT
VELOCITY RATIOS - VELOCITIES AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0°
TUBE COEFFICIENT
-NOTES-
VB - VELOCITY OF TUBE "B" AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0°
VR - VELOCITY OF STANDARD TUBE RESOLVED AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0°
VT - VELOCITY FROM VELOCITY-HEAD OF STANDARD TUBE RESOLVED AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0°
φ - TUBE COEFFICIENT - VR / VB
ANGLES FROM 0° - θ

Fig. 21.

TABLE NO. 3.

PITOT TUBE "C" AT VARIOUS ANGLES COMPARED TO STANDARD TUBE "A". DATE—9/24/10

Test	Angle of Tube "C" From 0° θ	Veloc. by Stand. Tube at 0° Ft. Per Sec. V	Veloc. by Tube "C" Ft. Per Sec. V_1	$V_c' = \frac{V_1}{V}$	Average V_c	Resolved Veloc. $V_R = \frac{V \cos\theta}{V}$	Tube Coefficient $\Phi = \frac{V_R}{V_c}$	REMARKS
85	0°	6.660	6.632	0.9958				
86	0°	6.180	6.133	0.9924	0.9943	1.0000	1.0057	
87	0°	6.720	6.685	0.9948				
88	5°	6.980	6.990	1.002				
89	5°	6.100	6.05	0.992	0.9970	0.9962	0.9992	
90	5°	6.210	6.19	0.997				
91	10°	6.395	6.375	0.997				
92	10°	6.490	6.46	0.996	0.9965	0.9848	0.9883	
93	10°	6.560	6.53	0.996				
94	10°	6.090	6.075	0.997				
95	15°	6.195	6.18	0.997	0.9970	0.9659	0.9688	Conditions exactly the same as for Tube "B" Table No. 2.
96	15°	6.320	6.30	0.997				
97	20°	6.320	6.24	0.988				
98	20°	6.140	6.07	0.989	0.9897	0.9397	0.9495	
99	20°	5.820	5.77	0.992				
100	25°	5.730	5.582	0.974	0.9730	0.9063	0.9315	
101	25°	5.920	5.755	0.972				
102	30°	6.010	5.62	0.935				
103	30°	5.682	5.342	0.940	0.9387	0.8660	0.9226	
104	30°	5.915	5.56	0.941				
105	35°	5.920	5.29	0.894	0.8955	0.8192	0.9148	
106	35°	5.850	5.25	0.897				
107	40°	6.460	5.42	0.8393	0.8357	0.7660	0.9166	
108	40°	6.042	5.03	0.8325				
109	45°	5.638	4.307	0.7645	0.7587	0.7071	0.9320	
110	45°	5.880	4.425	0.7530				

Fig. 22 shows the same set of curves plotted for tube "*C*". This tube has no flat face to deflect the water obliquely when it is turned at an angle, and it is not difficult to predict that for small angles of inclination this tube will entrap practically as much pressure as when it is straight. There is no reason for this tube to follow the resolved pressure law, as its shape does not conform to the theory. The velocities corresponding to the heads recorded by this tube are plotted at V_c; and it should be noted that the curve remains horizontal from 0 deg. to 15 deg. The slight variation of these values from unity may have no significance as it is perhaps due to experimental error.

The large amount by which the curve for this tube differs from the V_R curve results in low values of ϕ. This tube is therefore a poor form to use when the object is to measure discharge; it could be well used however, in connection with another tube to determine the amount of turbulence in a stream or the average angle of obliquity, since tube "*C*" will tend to pick up

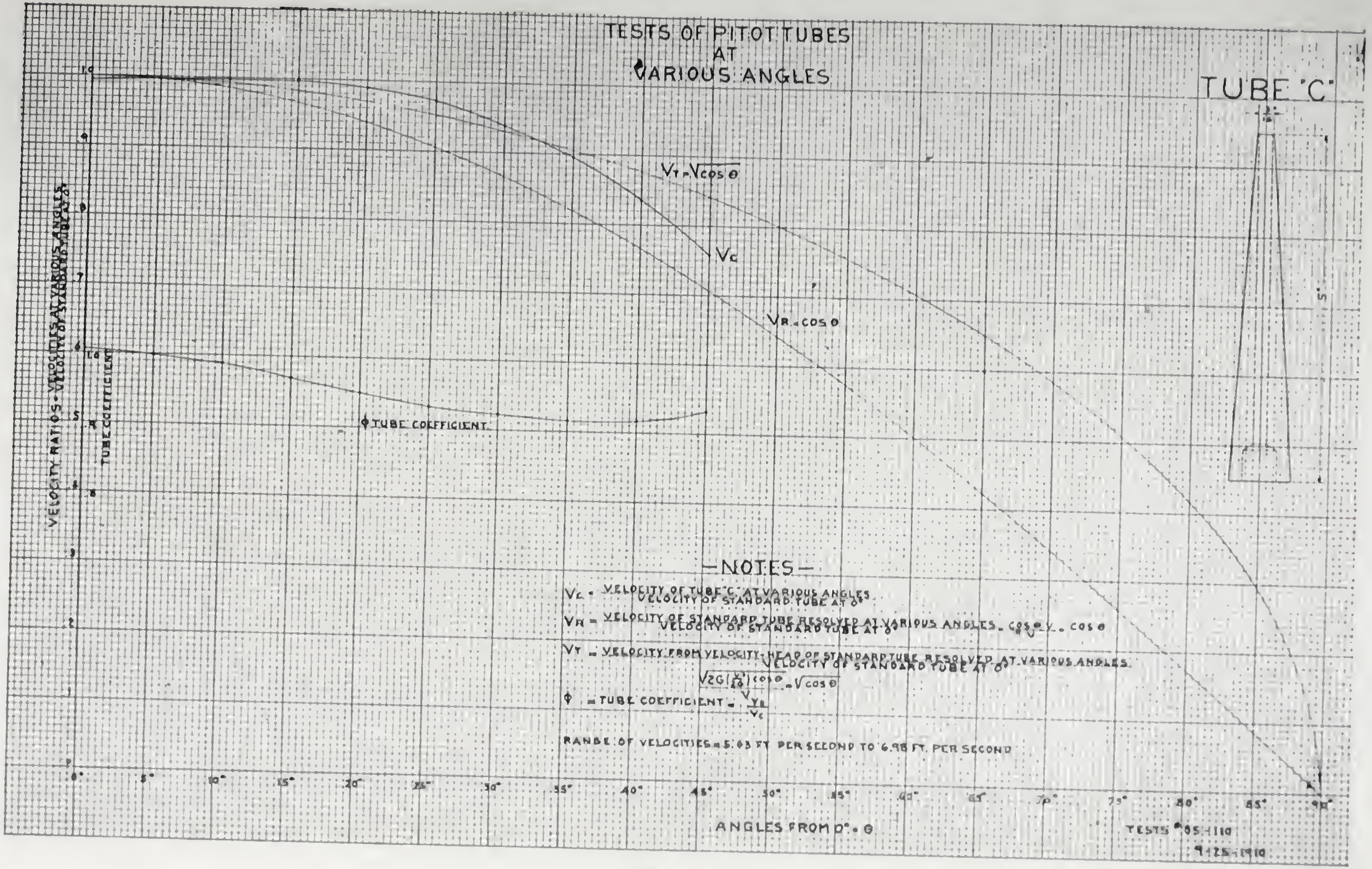

TESTS OF PITOT TUBES
AT
VARIOUS ANGLES
TUBE "C"
Vr - √cos θ
Vc
Vr - cos θ
ϕ TUBE COEFFICIENT
TUBE COEFFICIENT
VELOCITY RATIOS = VELOCITIES AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0°
—NOTES—
Vc = VELOCITY OF TUBE "C" AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0°
VR = VELOCITY OF STANDARD TUBE RESOLVED AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0° = cos θ
VT = VELOCITY FROM VELOCITY HEAD OF STANDARD TUBE RESOLVED AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0° = √cos θ
ϕ = TUBE COEFFICIENT = VR / Vc
RANGE OF VELOCITIES = 5.03 FT. PER SECOND TO 6.98 FT. PER SECOND
ANGLES FROM 0° = θ
TESTS #95-110
9-25-1910

Fig. 22.

the maximum velocity of the stream regardless of its direction, and will behave to some extent like the cup type of current meter.

TABLE NO. 4.

PITOT TUBE "D" AT VARIOUS ANGLES COMPARED TO STANDARD TUBE "A". DATE—9/26/10

Test	Angle of Tube "D" From 0° θ	Veloc. by Stand. Tube at 0° Ft. Per Sec. V	Veloc. by Tube "D" Ft. Per Sec. V_1	$V_D = \frac{V_1}{V}$	Average V_D	Resolved Veloc. $V_R = \frac{V \cos \theta}{V}$	Tube Coefficient $\Phi = \frac{V_R}{V_D}$	REMARKS
111	0°	5.025	5.000	0.9950				
112	0°	5.512	5.462	0.9909	0.9955	1.0000	1.0045	
113	0°	5.682	5.665	0.9970				
114	0°	6.480	6.475	0.9992				
115	5°R	5.655	5.635	0.9965				
116	5°R	5.322	5.295	0.9949	0.9934	0.9962	1.0028	
117	5°R	5.975	5.940	0.9941				
118	5°R	5.728	5.660	0.9881				Location of Tubes the same as for "B" & "C". Due however to Rain Depth of Water in Tank = 41⅛" Depth of Tube Points Below Surface = 20 9/16"
119	10°R	6.050	6.000	0.9917				
120	10°R	6.640	6.620	0.9970	0.9930	0.9848	0.9917	
121	10°R	5.938	5.900	0.9936				
135	10°L	6.245	6.220	0.9960				
136	10°L	5.704	5.645	0.9897				
137	10°L	6.165	6.122	0.9930				
138	10°L	6.107	6.040	0.9890				
122	15°R	6.445	6.403	0.9935				
123	15°R	6.247	6.202	0.9928	0.9927	0.9659	0.9730	
124	15°R	6.207	6.180	0.9956				
125	15°R	6.310	6.240	0.9889				All Angles θ Marked "R" were taken to the right and those Marked "L" to the left of the line of the Direction of Motion.
126	20°R	6.000	5.912	0.9853				
127	20°R	5.903	5.855	0.9919	0.9885	0.9397	0.9506	
128	20°R	6.022	5.942	0.9867				
139	20°L	7.005	6.900	0.9850				
140	20°L	6.048	5.992	0.9907				
141	20°L	5.940	5.890	0.9916				
129	25°R	5.984	5.890	0.9843				
130	25°R	6.065	5.932	0.9781	0.9822	0.9063	0.9227	
131	25°R	6.115	6.018	0.9841				
132	30°R	6.200	6.040	0.9742				
133	30°R	6.265	6.108	0.9749	0.9743	0.8660	0.8892	
134	30°R	5,865	5.682	0.9688				
142	30°L	5.936	5.804	0.9778				
143	30°L	6.341	6.200	0.9778				
144	30°L	6.100	5.932	0.9725				

Fig. 23, for tube *"D"*, shows curves of the same character as those of *"C"*, as might be expected from the form of *"D"*. In fact, this tube would be even better than *"C"* if used to record turbulence rather than velocity. It may be imagined that the action of the water on entering the funnel of *"D"* is nearly the same as that on *"C"* if the latter were made as large in diameter as the rim of *"D"*.

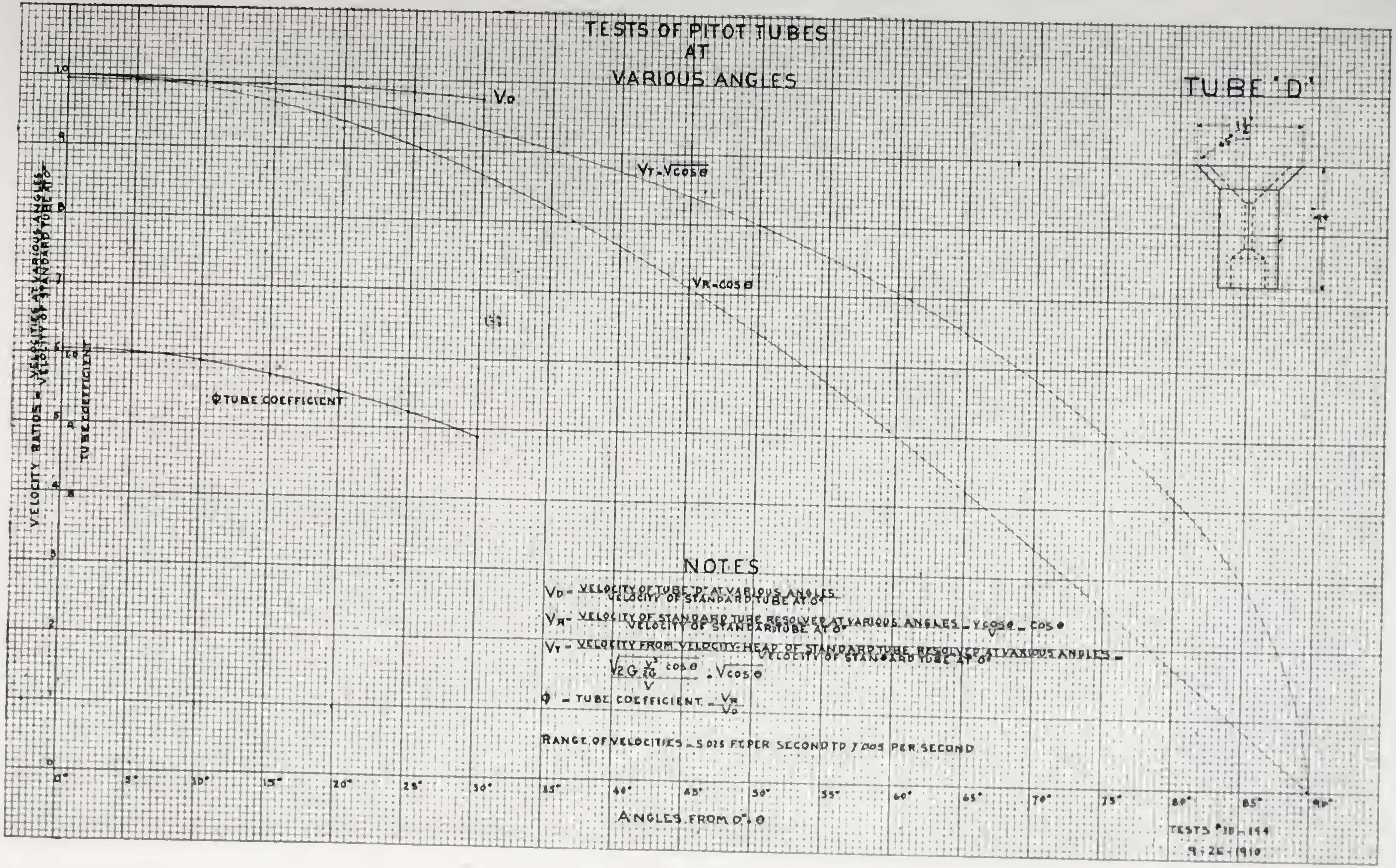

TESTS OF PITOT TUBES
AT
VARIOUS ANGLES
TUBE "D"
VELOCITY RATIOS = VELOCITIES AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0°
TUBE COEFFICIENT
V_D
$V_T = \sqrt{\cos\theta}$
$V_R = \cos\theta$
ϕ TUBE COEFFICIENT
NOTES
V_D = VELOCITY OF TUBE "D" AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0°
V_R = VELOCITY OF STANDARD TUBE RESOLVED AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0° = $\frac{V\cos\theta}{V} = \cos\theta$
V_T = VELOCITY FROM VELOCITY HEAD OF STANDARD TUBE RESOLVED AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0° = $\frac{\sqrt{2G\frac{V^2}{2G}\cos\theta}}{V} = \sqrt{\cos\theta}$
ϕ = TUBE COEFFICIENT = $\frac{V_R}{V_D}$
RANGE OF VELOCITIES = 5.025 FT. PER SECOND TO 7.005 PER SECOND
ANGLES FROM 0°, θ
TESTS #30-144
9-26-1910

Fig. 23.

TABLE NO. 5.

PITOT TUBE "E" AT VARIOUS ANGLES COMPARED TO STANDARD TUBE "A".

DATE—9/26 & 27/10

Test	Angle of Tube "E" From 0° Θ	Veloc. by Stand. Tube at 0° Ft. Per Sec. V	Veloc. by Tube "E" Ft. Per Sec. V_1	$V_E = \frac{V_1}{V}$	Average V_E	Resolved Veloc. $V_R = \frac{V \cos \Theta}{V}$	Tube Coefficient $\Phi = \frac{V_R}{V_E}$	REMARKS
145	0°	5.675	5.665	0.9982				
146	0°	5.085	5.090	1.0010				
147	0°	5.470	5.467	0.9994	0.99965	1.0000	1.00035	Conditions exactly
148	0°	5.465	5.465	1.0000				the same as for
149	5°R	5.985	5.995	1.0017				Tube D,
150	5°R	5.730	5.750	1.0035				Table No. 4.
151	5°R	5.920	5.910	0.9983				
152	5°R	5.873	5.883	1.0017	1.00125	0.9962	0.99495	
153	5°R	5.828	5.833	1.0009				
154	5°R	5.686	5.694	1.0014				
155	10°R	5.810	5.815	1.0009				
156	10°R	5.699	5.684	0.9974				
157	10°R	5.710	5.680	0.9947				
158	10°R	6.274	6.210	0.9898	.09958	0.9848	0.98895	
159	10°R	5.980	5.980	1.0000				
160	10°R	5.500	5.493	0.9987				
180	10°L	6.010	5.934	0.9874				
181	10°L	6.162	6.138	0.9961				
182	10°L	6.155	6.138	0.9972				
161	15°R	5.740	5.705	0.9939				
162	15°R	5.865	5.806	0.9900				
163	15°R	5.885	5.860	0.9958				
164	15°R	5.950	5.886	0.9893	0.9923	0.9659	0.97339	
165	15°R	6.175	6.115	0.9903				
166	15°R	5.565	5.535	0.9946				
167	20°R	5.800	5.680	0.9793				
168	20°R	5.622	5.496	0.9776				
169	20°R	5.865	5.745	0.9795				
170	20°R	5.665	5.564	0.9822				
183	20°L	6.282	6.072	0.9666	0.9742	0.9397	0.9645	
184	20°L	6.350	6.162	0.9704				
185	20°L	6.195	6.021	0.9719				
186	20°L	6.218	6.008	0.9663				
171	25°R	5.900	5.622	0.9529				
172	25°R	6.050	5.800	0.9587				
173	25°R	6.080	5.821	0.9574	0.9555	0.9063	0.9485	
174	25°R	6.380	6.080	0.9530				
175	30°R	6.392	5.944	0.9298				
176	30°R	5.772	5.320	0.9217				
177	30°R	6.130	5.660	0.9233				
178	30°R	5.952	5.500	0.9241				
179	30°R	6.621	6.085	0.9191				
187	30°L	6.240	5.670	0.9087				
188	30°L	6.212	5.680	0.9143	0.9172	0.8660	09441	
189	30°L	6.275	5.700	0.9084				
190	30°L	6.842	6.240	0.9120				
191	30°L	6.844	6.235	0.9110				
192	40°R	6.692	5.508	0.8231				
193	40°R	6.870	5.692	0.8286				
194	40°R	6.860	5.689	0.8293	0.8273	0.7660	0.9259	
195	40°R	6.792	5.625	0.8281				
196	50°R	7.235	4.970	0.6868				
197	50°R	5.775	3.950	0.6838				
198	50°R	6.145	4.217	0.6863	0.6840			
199	50°R	5.980	4.062	0.6793				
200	60°R	6.114	2.852	0.4665				
201	60°R	6.050	2.780	0.4595	0.4630			
202	70°R	6.305	0.543	0.0861				
203	70°R	6.680	1.008	0.1508	0.1131			
204	70°R	7.148	0.732	0.1024				
205	80°R	6.135	−2.700	−0.4400				
206	80°R	6.415	−2.932	−0.4572				
207	80°R	6.275	−2.780	−0.4430	−0.44885			
208	80°R	6.490	−2.953	−0.4552				
209	90°R	6.530	−5.780	−0.8852				
210	90°R	6.365	−5.732	−0.9006				
211	90°R	6.645	−5.882	−0.8852	−0.89315			
212	90°R	6.438	−5.805	−0.9016				

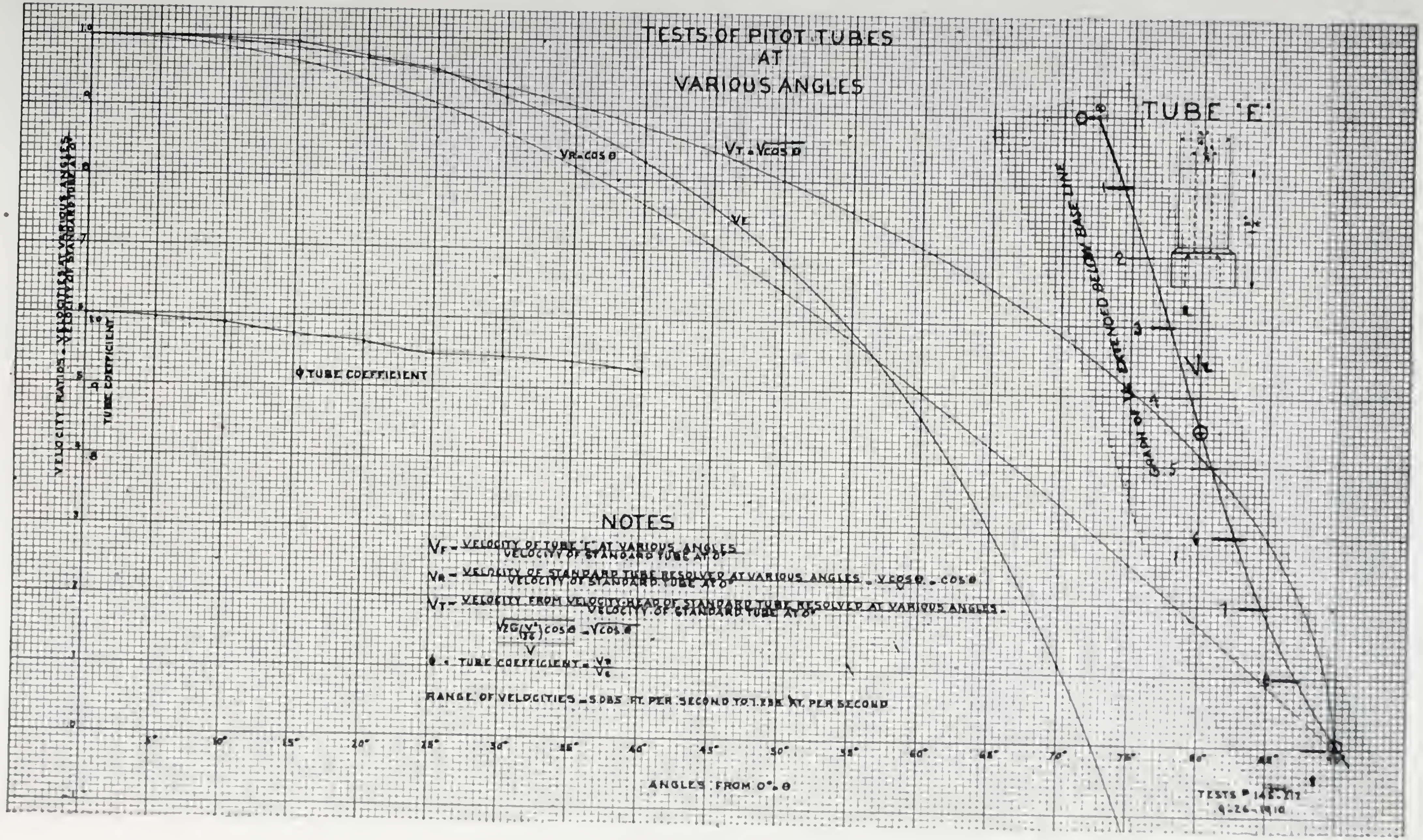

TESTS OF PITOT TUBES
AT
VARIOUS ANGLES
TUBE "E"
VELOCITY RATIOS = VELOCITIES AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0°
TUBE COEFFICIENT
φ TUBE COEFFICIENT
VR = COS θ
VT = √COS θ
VE
GRAPH OF VE EXTENDED BELOW BASE LINE
NOTES
ANGLES FROM 0° = θ
TESTS # 143-172
9-26-1910

Fig. 24.

Tube "*E*" is perfectly cylindrical on the outside, and the tests on this tube and also on "*F*" were carried farther than on the others, the inclination being continued up to 90 deg. as shown in Fig. 24. The great amount of suction produced in the 90 deg. position—the negative pressure being almost equal to the velocity head of the water—indicates the large error which results when static pressure peizometer tubes are allowed to project beyond the inner surface of a pipe. Such a tube as this would have to be turned 17½ deg. upstream to record the exact static pressure, free from velocity influence; but even in this position it would be a poor instrument, because a slight variation in angle would cause a rapid variation in the reading.

The character of the curves of "*E*" for small angles is similar in general to tube "*B*" and the curve V_F is seen to agree fairly well with the theoretic curve V_T for angles up to 30 deg.

Tube "*F*", the curves of which are shown in Fig. 25, is one of the most interesting of those tested. The curve for this tube, V_F shown in Fig. 25, is in close agreement with the theoretic curve V_T for moderate angles of inclination, and differs from it less than one percent between 0 deg. and 30 deg. After this the disturbances on the cylindrical lateral surface of the tube probably begin to be felt, and the pressure drops below that corresponding to V_T. This tube develops much less negative pressure in the 90 deg. position than tube "E", and it can be judged that if the diameter is increased to furnish a flat plate of sufficient extent and the edge disturbance avoided, the true static pressure will be recorded. It is evident, however, that disturbances in the neighborhood of the static opening cause large errors in a peizometer.

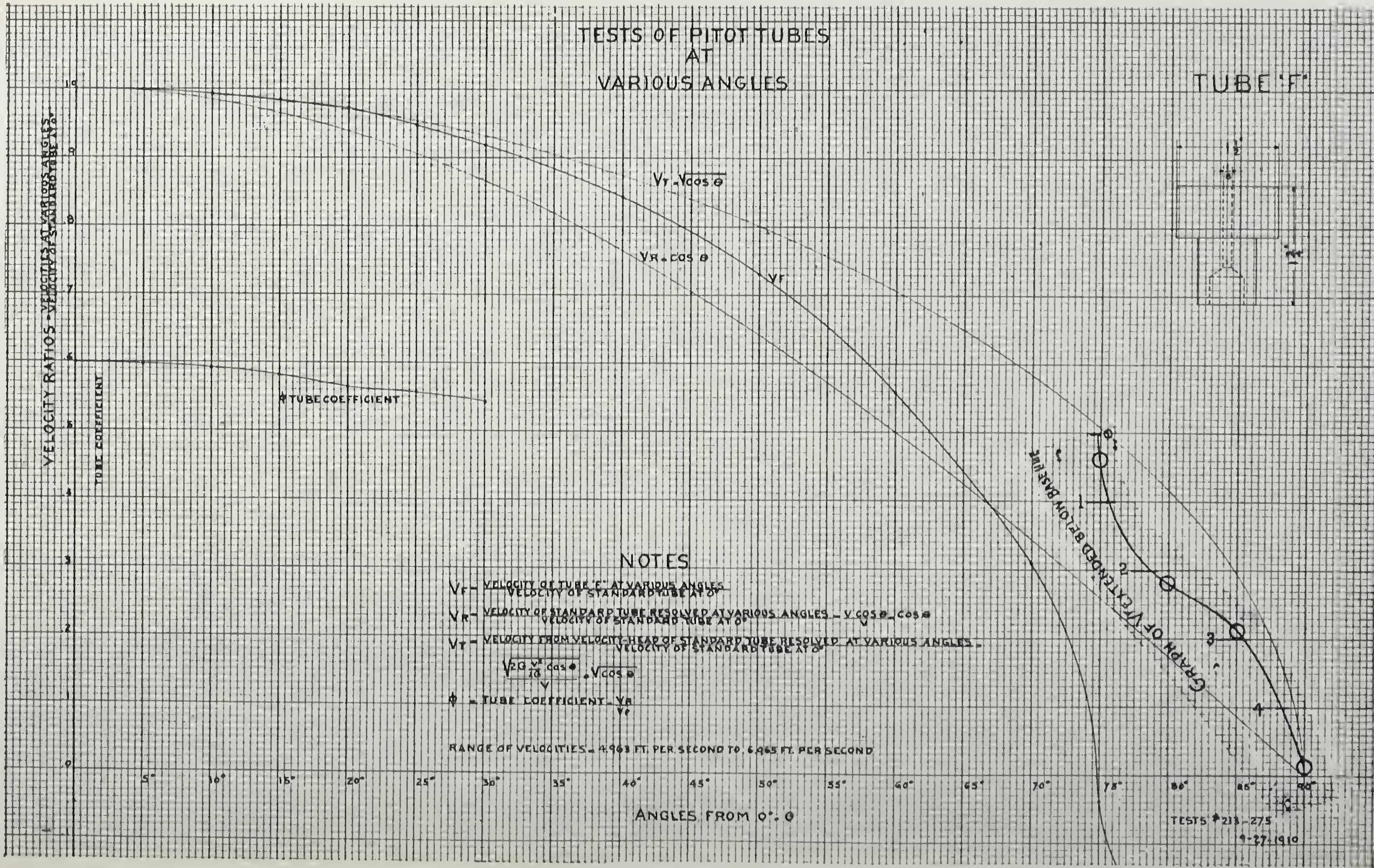
The results of the oscillating tests were somewhat inconclusive on account of the difficulty in obtaining accurate readings as noted above, so that these tests are omitted. It may be said, however, that the effect of the oscillations on the pressure recorded by the tube seemed to be slight and only at high velocities of oscillation was the effect clearly developed. At the higher reciprocating velocities, the oscillations being in the direction of motion of the car, the tube read too high, so that under conditions in a stream involving variation in magnitude

TABLE NO. 6.

PITOT TUBE "F" AT VARIOUS ANGLES COMPARED TO STANDARD TUBE "A".

DATE—9/27/10

Test	Angle of Tube "F" From 0° Θ	Veloc. by Stand. Tube at 0° Ft. Per Sec. V	Veloc. by Tube "F" Ft. Per Sec. V_1	$V_F = \frac{V_1}{V}$	Average V_F	Resolved Veloc. $V_R = \frac{V \cos \Theta}{V}$	Tube Coefficient $\Phi = \frac{V_R}{V_F}$	REMARKS
213	0°	5.798	5.810	1.0027				
214	0°	5.682	5.685	1.0005				
215	0°	5.870	5.880	1.0017	1.0010	1 0000	0.9990	
216	0°	6.315	6.310	0.9992				
217	5°R	6.180	6.153	0.9956				
218	5°R	6.153	6.145	0.9987				
219	5°R	6.161	6.165	1.0006	0.99998	0.9962	0.9962	
220	5°R	5.540	5.562	1.0040				
221	5°R	5.437	5.443	1.0010				Conditions the same as for Tubes D & E, Tables 4 & 5.
222	10°R	5.663	5.638	0.9956				
223	10°R	5.703	5.655	0.9916				
224	10°R	5.500	5.455	0.9918	0.9928	0.9848	0.9919	
225	10°R	5.680	5.635	0.9921				
226	15°R	5.400	5.335	0.9880				
227	15°R	5.540	5.440	0.9820	0.9839	0.9659	0.9817	
228	15°R	5.272	5.162	0.9792				
229	15°R	5.758	5.681	0.9866				
230	20°R	5.518	5.360	0.9714				
231	20°R	5.920	5.760	0.9730				
232	20°R	5.980	5.845	0.9774				
233	20°R	6.096	5.940	0.9744	0.9730	0.9397	096578	
234	20°R	6.315	6.120	0.9691				
235	20°R	6.200	6.032	0.9729				
236	25°R	6.271	6.000	0.9568				
236	25°R	6.025	5.685	0.9436				
238	25°R	5.940	5.618	0.9458	0.9467	0.9063	0.95732	
239	25°R	6.385	6.020	0.9429				
240	25°R	6.520	6.158	0.9445				
241	30°R	6.460	5.930	0.9180				
242	30°R	6.828	6.315	0.9248				
243	30°R	6.305	5.805	0.9207	0.9179	0.8660	0.9435	
244	30°R	6.420	5.875	0.9151				
245	30°R	6.418	5.845	0.9108				
246	40°R	6.460	5.446	0.8431				
247	40°R	6.620	5.575	0.8422	0.8433			
248	40°R	6.348	5.360	0.8445				
249	50°R	6.440	4.675	0.7259				
250	50°R	6.495	4.760	0.7328	0.7300			
251	50°R	6.835	5.000	0.7313				
252	60°R	6.735	3.840	0.5702				
253	60°R	6.795	3.810	0.5606	0.5593			
254	60°R	6.330	3.463	0.5472				
255	70°R	8.265	2.037					
256	70°R	6.535	2.045	0.3130	0.3098			
257	70°R	6.840	2.097	0.3066				
258	75°R	6.965	0.954	0.1369				
259	75°R	6.541	0.750	0.1146				
260	75°R	6.150	—0.834	—0.1356	—0.0386			
261	80°R	6.500	—1.445	—0.2222				
262	80°R	6.458	—1.426	—0.2210	—0.2196			
263	80°R	6.440	—1.389	—0.2156				
264	85°R	6.240	—1.778	—0.2849				
265	85°R	6.355	—1.822	—0.2868	—0.2887			
266	85°R	6.282	—1.851	—0.2945				
267	90°R	6.320	—2.750	—0.4351				
268	90°R	6.265	—3.137	—0.5002				
269	90°R	6.755	—2.966	—0.4390				
270	90°R	6.660	—3.343	—0.5020				
271	90°R	4.693	—2.407	—0.5124				
272	90°R	5.005	—2.472	—0.4938	—0.4781			
273	90°R	4.977	—2.523	—0.5070				
274	90°R	4.902	—2.442	—0.4982				
275	90°F	4.780	—2.371	—0.4960				



TESTS OF PITOT TUBES
AT
VARIOUS ANGLES
TUBE 'F'
VELOCITY RATIOS - VELOCITIES AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0°
TUBE COEFFICIENT
φ TUBE COEFFICIENT
VT = √cos θ
VR = cos θ
VF
GRAPH OF VF EXTENDED BELOW BASE LINE
NOTES
VF = VELOCITY OF TUBE 'F' AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0°
VR = VELOCITY OF STANDARD TUBE RESOLVED AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0° = V cos θ / V = cos θ
VT = VELOCITY FROM VELOCITY-HEAD OF STANDARD TUBE RESOLVED AT VARIOUS ANGLES / VELOCITY OF STANDARD TUBE AT 0° = √(2G v²/2G cos θ) / V = √cos θ
φ = TUBE COEFFICIENT = VR / VF
RANGE OF VELOCITIES = 4.963 FT. PER SECOND TO 6.965 FT. PER SECOND
ANGLES FROM 0° - θ
TESTS #213-275
9-27-1910

Fig. 25.

of the velocity, the velocity recorded by the tube must be multiplied by a coefficient less than unity, as previously predicted. For a given maximum velocity of oscillation, the effect of a low number of long oscillations per second was greater than oscillations of less amplitude with a corresponding increase in the number per second. In other words the tests seemed to indicate that small rapidly recurring variations in the magnitude of the velocity do not cause any appreciable error in the tube reading.

A rapidly recurring variation in the angle at which the water impinged on the tube, as was given by the transverse reciprocating tests, seemed to have little effect on the tube reading, while a constant angle of obliquity caused the tube to read too high, as we have just seen.

The conclusion to be drawn from these tests is that in streams having turbulent flow, the Pitot tube will read slightly too high a velocity, due to the effect of deviations in the direction of flow of the water from the direction normal to the section of measurement, and to variations in the magnitude of the velocity. This result shows that under ordinary conditions of flow, a coefficient lower than unity must be used to reduce the velocities indicated by the tube to values which will give the true discharge. The amount of this coefficient can be obtained by determining the average obliquity of flow by the use of the tube in connection with a second tube or current meter.

The I. P. Morris Company has obtained a number of reliable tests in both large and small pipes, in which the discharge has been measured simultaneously by Pitot tubes in the pipe and by weirs or weighing tanks. The coefficients to be used with the tube at ordinary velocities in large penstocks as indicated by weir tests at Niagara Falls and Shawinigan Falls, should be slightly less than 98 percent; the average value used by the I. P. Morris Company being 0.9763. These results were also checked by careful tests made on smaller pipes at the University of Pennsylvania hydraulic laboratory. In these tests the water was measured in large weighing tanks. The coefficient was in every case less than unity.

The best form of tube to use, as shown by the still-water tests, is a flat-faced, or blunt, tube similar to "*A*", "*B*" or "*E*", since these tubes are less affected by oblique flow than the sharp pointed or funnel-shaped types. The Morris Company uses tubes similar to "*A*" or "*B*", and the above value of the coefficient is applicable with such a tube. When used with this coefficient, it is believed that the Pitot tube will measure discharge with an error of a small fraction of one percent.

COMPARATIVE PERFORMANCE OF PITOT TUBE AND CURRENT METERS

In a valuable thesis presented to the Rensselaer Polytechnic Institute for the degree of Civil Engineer, in 1912 [4], Mr. Charles F. Rumpf has described a long series of tests made by him at the Institute rating tank, the apparatus described above being used.

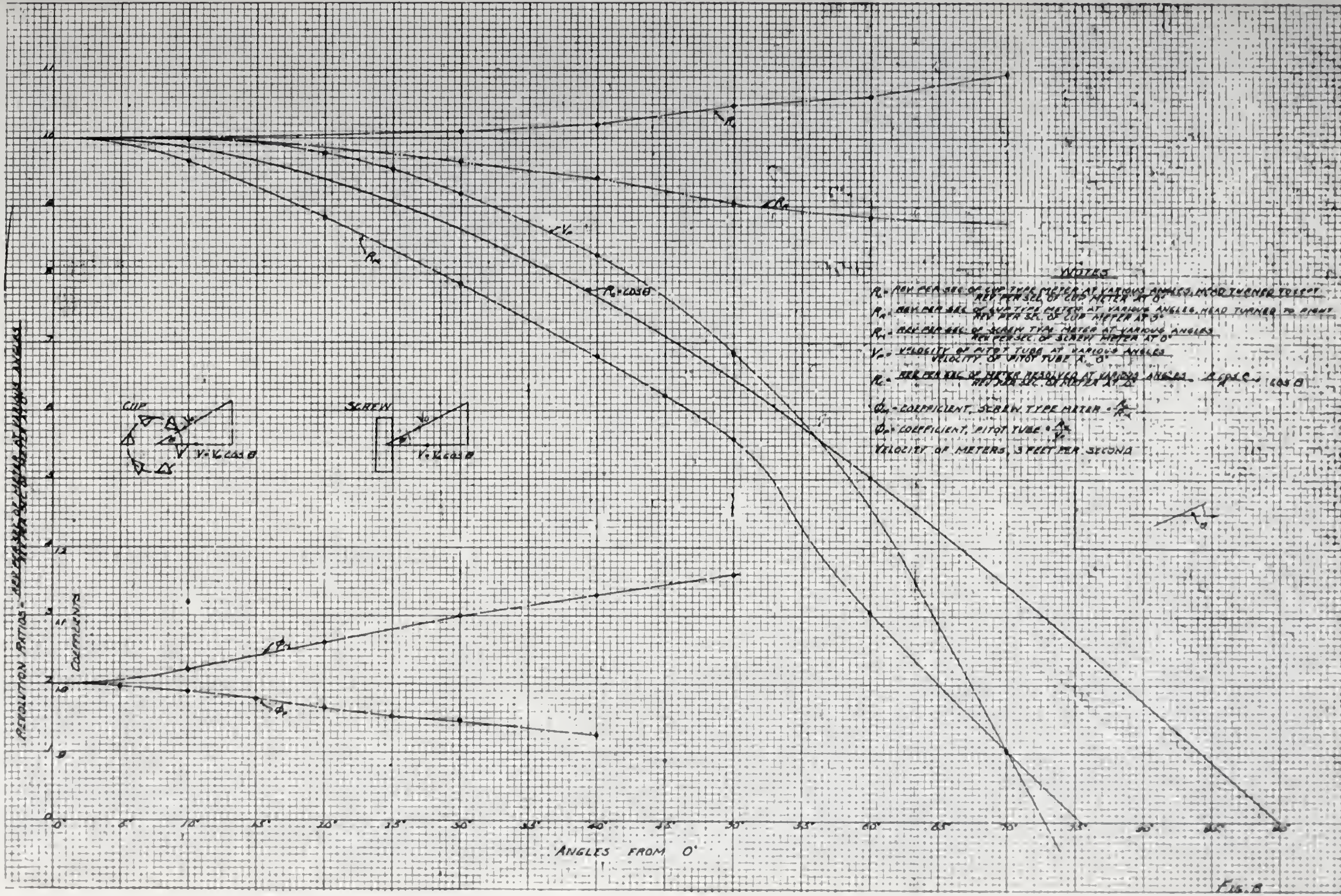
In addition to many tests of various other factors affecting the operation of current meters, the meters were turned at various angles and the tests already described for Pitot tubes were duplicated with current meters. Two meters were used, a Price[5] meter of the cup type, and a Buff & Berger screw meter of the Fteley-Stearns type. The results of these experiments are shown in Fig. 26, (Fig. 8 of thesis) which shows curves plotted in the same manner as those of Figs. 21 to 25.

It will be seen from this curve that the cup meter gives different readings for velocities inclined to the right from those inclined to the left, as shown in curves R_L and R_R. The mean of these curves falls close to unity at all angles, showing that this meter records practically the maximum velocity in the stream irrespective of direction. The screw meter, however, gives readings which are too low when compared with the resolved velocity corresponding to any degree of obliquity, as shown by the fact that the curve of this meter, R_M falls considerably below the cosine curve, R_C. The curve for the Pitot tube marked V_P, is the curve for tube "*E*" repeated, and is the same as curve V_E in Fig. 24.

The coefficients which should be used with the screw meter are shown in the curve ϕ_M, and since this meter would give deficient readings in turbulent water the coefficients are greater

[4] "An Investigation into the Use and Rating of the Current Meter" by Charles F. Rumpf. This thesis was awarded the MacDonald prize.

[5] Small Gurley acoustic meter converted for electric recording.



NOTES
VELOCITY OF METERS, 3 FEET PER SECOND
ANGLES FROM 0°
CUP
SCREW
COEFFICIENTS

Fig. 26.

than unity. The coefficients for Pitot tube "*E*" are marked ϕ_E and are the same as shown at ϕ in Fig. 24. It will be noticed that either type of current meter gives results which differ from the desired curve, R_c, by a considerable margin, and that the Pitot tube is better in this respect than the meters and can be used with a coefficient much nearer to unity.

It is inherent in the cup type of meter to read too high in turbulent water. The characteristics of the screw meter, can, however, be greatly modified by changes in the design.

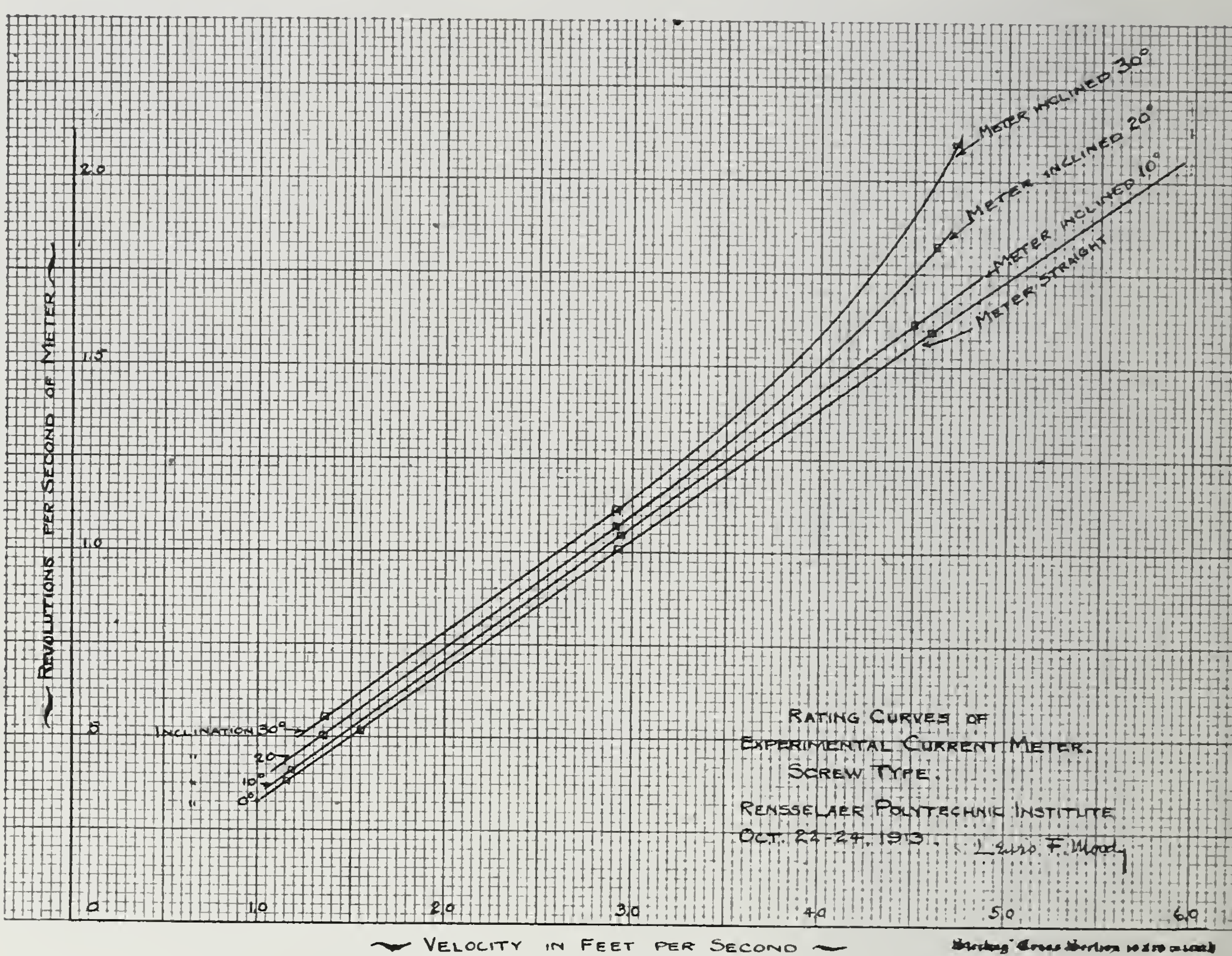


Fig. 27.

In this connection it may be of interest to refer to the curve of a screw meter of a peculiar type recently tested by the writer, as given in Fig. 27. This screw meter, instead of having its readings reduced by turbulence will show an increase in revolutions greater even than given by the cup meter. Turning this meter at an angle not only failed to reduce the revolutions in the ratio of the cosine of the angle, but actually increased them. A further peculiar feature is that the rating curve of the meter in an inclined position is not a straight line.

CONCLUSION: METHOD OF APPLYING PITOT TUBE

In conclusion it may be said that the Pitot tube has been found to be an extremely useful instrument for many diverse uses. It may be applied to practically any fluid, to air or gas as well as to liquids; can be used in either closed pipes or open channels, and in either large or small streams. When applied to the measurement of pipe discharge, two or more tubes are inserted through stuffing boxes so that they can be moved to various stations across two perpendicular diameters of the pipe. The method of the writer for determining the discharge has been previously described.[6]

This method consists, briefly, in the plotting of the velocity at each point of the diameter as ordinates of a curve, the abscissas of which instead of being proportional to the distances of the tube from the center of the pipe, are proportional to the squares of these distances. The abscissa of any point is therefore proportional to the area of the portion of the pipe cross-section contained within a circle drawn through the corresponding position of the tube. The total area under the curve will represent, to the proper scale, the value of $\int v\ da$; and this is the discharge from the pipe. If the plotted velocities are those computed from $v = \sqrt{2g \times \textit{reading of Pitot tube}}$, then the result should be multiplied by a coefficient less than unity to give the true discharge. This method has been used in a large number of important tests.

It is suggested that the graphical method of computing discharge could be easily applied to irregular open channels. The stream cross-section would be divided into a number of vertical strips in the usual manner, and the mean velocity for each ordinate between successive strips found by means of current meters or Pitot tubes. This mean velocity at any station could be obtained either graphically from point determinations, or from integrating traverses with a meter. The mean velocities at each station would then be plotted as the ordinates of a curve, the abscissa of any point being the sum of the areas of all the strips to the left of the station, or the total area of the cross-section to the left of the vertical considered. The area under the curve so plotted would then represent to scale the integral of the product: *velocity* $\times$ *differential area*, or the total discharge.

[6] "A New Method of Reducing the Readings of the Pitot Tube", by W. M. White. American Machinist, Arg. 9, 1906, p. 175.

PITOT TUBE FORMULAS
FACTS AND FALLACIES

By Benjamin Feland Groat*

Discussion by Messrs. Gardner S. Williams, W. M. White, N. C. Grover, Clemens Herschel, William Kent, Edward S. Cole, Morris Knowles, Thomas P. Roberts, Charles M. Allen, Robert Linton, Herman Bacharach, F. Nagler, E. H. Brown, J. S. Beresford, John N. Chester, Lewis F. Moody, and Benjamin F. Groat.

Although the hydrodynamic reactions associated with the Pitot tube have been most thoroughly treated in our best works upon hydrodynamics, yet it does not seem that the important theorems established have always been respected by those who have used the instrument or discussed its theory. During the last fifteen years certain fallacies have found provisional acceptance by a number of text-book writers, while others have taken care to avoid applications of theories of any kind. Concurrently there have appeared occasional discussions by eminent engineers showing an astonishing difference of opinion as to whether the head raised in a Pitot tube is equal to the velocity-head of the impinging water or to twice that velocity-head.

It is not clear why there should be any difference of opinion among hydraulists as to the question last mentioned. Bernoulli's theorem is generally accepted as it applies to the flow of water in pipes, and it would seem that it should apply with closer approximation to the flow of water in an open channel in the immediate vicinity of a Pitot tube, since the effects of friction would be almost negligible. Moreover, as applied to pipes, the theorem has been employed in connection with the mean velocity in the pipe instead of the actual velocity at a point. If the laws of hydrodynamics are to be thus applied

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then there is no room for the contention that the head raised in a Pitot tube is twice the velocity-head of the impinging water.

Again, it has been claimed that neither of the two theories mentioned is correct, for the effects of eddies and friction would tend to cut down the head so as to vitiate either of the resulting formulas. This is, in reality, not a valid argument because a theory in mechanics may take into account only part of the forces and reactions actually present, leaving the remainder to be covered by the introduction of additional forces and reactions, or to be represented by experimental coefficients for

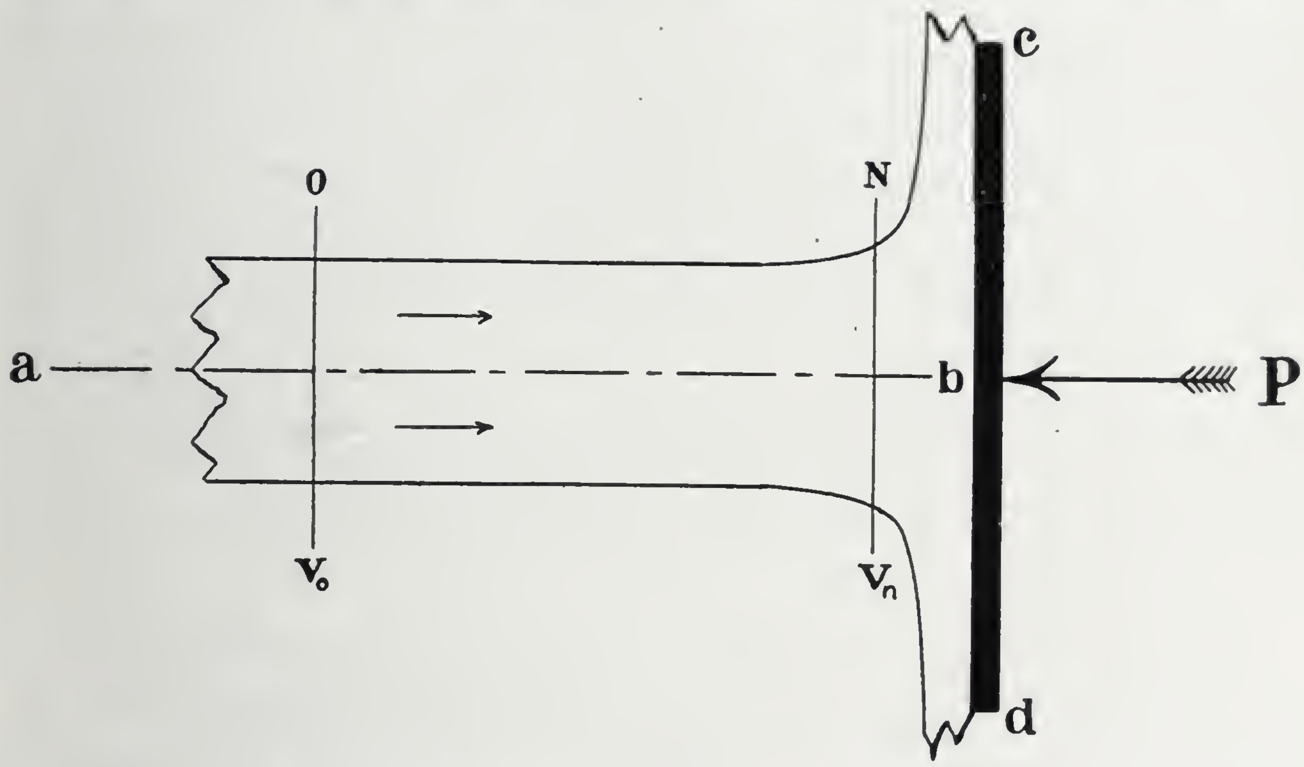


Fig. 1. Action of a Jet Upon a Plate.

limited ranges of conditions approximating more or less closely the ranges encountered in practice. If a theory treats of an ideal, or so-called perfect fluid, and is correct from the standpoint of pure mechanics, it will not be useless to the trained engineer because incomplete. He may, however, find it necessary to make a special study in order to introduce the effects of the disturbing influences not considered in the construction of the ideal formula. In fact this is just where the profession of Engineer finds its best foundation. Namely, the anticipation of future experiences from those that are past.

With these prefatory remarks it will be well to state briefly the object and scope of the paper. It is the intention first to give a simple proof of the formula, $h = v^2 \div 2g$, in its

relation to the formula, $h = v^2 \div g$, and to show that the former applies to the Pitot tube while the latter applies to the case of a jet impinging perpendicularly upon a plane surface. In both these cases the actual maximum pressure-head developed in the water is $v^2 \div 2g$ but the total pressure on the plane surface, *if divided by the numerical value of the area of the jet,* would be equivalent to an average pressure-head represented by $v^2 \div g$. This average pressure-head is merely an ideal quantity as, indeed, all averages are. In practice the actual maximum pressure-head in the water impinging perpendicularly upon a plane surface will be found to be a trifle, though a surprisingly small trifle, less than half of the average derived in the manner described. Second, it will be shown that the foregoing statements are supported by all the experiments of a long line of able investigators.[1] Third, the general results of experiments by the writer while conducting an elaborate series of turbine tests will be given, together with the method of determining the coefficient of a Pitot tube by comparison of its records with the corrected records of two different types of current meter when these records are derived from the variable velocities of a tail race.

[1]The Pitot tube was invented by Henri Pitot in 1730 and is described in *Histoire de l' Academie des Sciences,* 1732, p. 376. Darcy obtained unity for the coefficient in his experiments, *Recherches Hydraulics,* Darcy and Bazin, 1865, p. 63. J. S. Beresford obtained unity in his experiments for the coefficient, 1878, referred to elsewhere in this paper. The writer understands that the unpublished results of Hiram Mills, Hon. M. Am. Soc. C. E., are probably the most exhaustive of all and substantially verify the formula, $v^2 = 2\ gh$, as the relation between velocity and head indicated by the Pitot tube. More recently have appeared a number of papers, among which may be mentioned numerous papers and discussions by Gardner S. Williams including his prize paper in the Transc. Am. Soc. C. E., Vol. XLVII., p. 1; the prize papers by John R. Freeman in the Transc. Am. Soc. C. E., Vol. XXI., p. 303 and Vol. XXIV., p. 492; the experiments of W. M. White in 1900 referred to elsewhere herein; W. B. Gregory, Transc. Am. Soc. M. E., 1903; Boyd and Judd in Engineering News, Vol. 51, 1904, p. 318; Judd and King in Engineering News, Sept. 27, 1906, p. 326; "Nozzle Piezometer", F. B. Sanborn, Engineering News, Sept. 13, 1906, p. 271; and many others. See also "Notes on the Pitot Tube" by John Airey, Engineering News, April 17, 1913, with discussion by A. E. Guy and the writer in the issues of May 22, June 5, and July 31, following. There are also numerous papers upon the Pitot tube as applied to the measurement of the flow of gases, some of which are not yet published. T. E. Stanton "On the Resistances of Plane Surfaces in a Current of Air", Proceedings, Institution of Civil Engineers, 1904, 156; an excellent paper by W. C. Rowse in the September 1913 Journal Am. Soc. M. E.; experiments by Professors A. M. Greene, Jr., and Lewis F. Moody at Rensselaer Polytechnic Institute.

ACTION OF JET UPON A PLATE

Let Fig. 1 represent a jet *ab* of water acting upon the plate *cd* having its plane perpendicular to the axis of the jet.

Let

A = cross-sectional area of jet at O;
v_o = velocity of jet at O;
v_n = component of velocity perpendicular to plane of plate at N;
w = weight of a cubic unit of water;
g = acceleration of gravity;
P = total force retarding the water.

Then the mass flowing per second through the section O, multiplied by the change in velocity between sections O and N, will be the time rate of change in momentum between sections O and N. Therefore, this product will be equal to the total force acting to retard the velocity of the water between sections O and N.

Hence,

$$\text{Mass per second} = \frac{wAv_o}{g}$$

$$\text{and velocity change} = v_o - v_n;$$

$$\text{Therefore, } P = \frac{wAv_o}{g}(v_o - v_n) \dots\dots\dots\dots\dots (1)$$

Now since v_n is the component velocity of jet perpendicular to plane of plate it must equal zero at the surface of the plate.

$$\text{Therefore, } P = wA\,\frac{v_o^2}{g} \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

No exception can be taken to equation (2) because it is theoretically correct and has been demonstrated by experiment on many occasions and by experimentalists of unquestioned skill. We may now go a step further and write

$$\left.\begin{array}{l}\textit{Intensity of pressure on a sur-}\\ \textit{face equal to the area of the jet}\end{array}\right\} = p_1 = \frac{P}{A} = w\,\frac{v_o^2}{g} \dots\dots (3)$$

or still further and write

$$\left.\begin{array}{l}\text{Head which such a pressure}\\ \text{would support } \textit{if it acted uni-}\\ \textit{formly over an area equal to}\\ \textit{that of the jet}\end{array}\right\} = h_1 = \frac{P}{wA} = \frac{v_o^2}{g} \dots\dots (4)$$

Now the intensity of pressure, p, of equation (3) and the

head, h, of equation (4) are purely ideal quantities because they are based upon the *assumptions* that the pressure is confined to an area equal to the area of the jet and that it is uniform.

That this pressure is not uniform may be proved by boring small holes in the plate perpendicular to its face and measuring the pressures through these holes by manometer tubes. If this is accurately done the intensity of pressure at the center will be found to be almost exactly one-half that given by (3).[2]

It may also be shown experimentally, that the pressure acts over an area *greater* than the area of the jet, by making the area of the plate equal to that of the jet. It will then be found that the total pressure is less than that given by equation (3). It will also be observed that the water in this experiment is not diverted through an angle of 90 deg., but through a much smaller angle. This shows that, when the plate is larger than the area of the jet, *as it must be in order to divert the water through 90 deg. and develop the full reaction,* there is a region of pressure extending beyond an area A projected upon the plate.

These experimental facts prove unqualifiedly that the intensity of pressure of a jet of water upon the face of a plate is always and everywhere upon the plate less than $wv^2 \div g$.

Moreover, the experiment of taking the manometer pressures through holes in the plate shows that the pressure upon the surface of the plate is nowhere greater than $wv^2 \div 2g$, *equaling this value at the center and diminishing radially therefrom in all directions.*

EXPERIMENTAL DETERMINATION OF THE DISTRIBUTION OF PRESSURE OVER A PLANE SURFACE UPON WHICH A JET OF WATER IMPINGES

Figure 2 exhibits typical curves of pressure as obtained by William Monroe White in America and J. S. Beresford in In-

[2]Experiments by W. M. White, in 1901. See Journal, Association of Engineering Societies, Vol. 27, p. 39. Also experiments by J. S. Beresford in Professional Papers on Indian Engineering, No. CCCXXII, mentioned by W. C. Unwin in his article "Hydraulics" in the Eleventh Edition of The Encyclopædia Britannica, Vol. 14, p. 90. These experiments were conducted at Naini, Tal. in October 1878, to determine the intensity and distribution of the pressure of a jet of water against a fixed plane surface. This paper was abstracted in Minutes of the Institution of Civil Engineers, Vol. 60, 1880.

dia. The curve obtained by Mr. White from Observation *VI* is shown on the left while similar curves as obtained by J. S. Beresford are shown on the lower right. Through some mischance the numerals *I* and *III* upon the latter curves have been transposed, so that the curve marked "Exper. *III*" relates to experiment *I* while the curve marked "Exper. *I*" relates to experiment *III*.* To make this matter perfectly clear, a reproduction of Mr. Beresford's curves for these experiments, taken from his paper, is supplied in Fig. 2a. The curve on the upper right, Fig. 2, is the one at the top of page 9, vol. 14, Encylopædia Britannica, and illustrates very clearly the general character of such curves. The reader will not fail to notice the resemblance to the well known Probability Curve. The fact that the maximum rise of these curves brings the vertex practically up to the level of the water in the reservoir shows that the experiments demonstrate the practical equality of the pressure-head, at the center of the plate, to the velocity-head of the jet issuing from the orifice as it impinges upon the plate. It should also be observed that the pressure falls to negligible values at a distance from the axis of the jet equal to the diameter of the jet. Thus the portion of the area of the plate which sustains any appreciable pressure is about four times the sectional area of the jet. The striking similarity of the experiments by

*Besides these errors in the article "Hydraulics" Fig. 168, p. 90, Eleventh Edition, Encyclopædia Britannica, the writer has discovered two others of greater moment in the same article. The most serious one is the value of the coefficient of viscosity for water at 77 deg. Fahr., which is stated to be 0.00 000 191 in lbs. per sq. ft. per unit transverse velocity gradient in feet per second. (See p. 35, upper right.)

The correct equation for this in *C. G. S.* units is

$$\text{Coefficient of viscosity (for water)} = \frac{0.0178}{1 + 0.0037\,t + .000\,221\,t^2}$$

t being in centigrade degrees. (See p. 536, Lamb's "Hydrodynamics", 1906.)

If the formula is transformed so as to involve the foot, pound and Fahrenheit degree it becomes

$$\text{Coefficient of viscosity (for water)} = \frac{0.0\,000\,372}{0.47 + 0.0144\,t + 0.000\,068\,t^2}$$

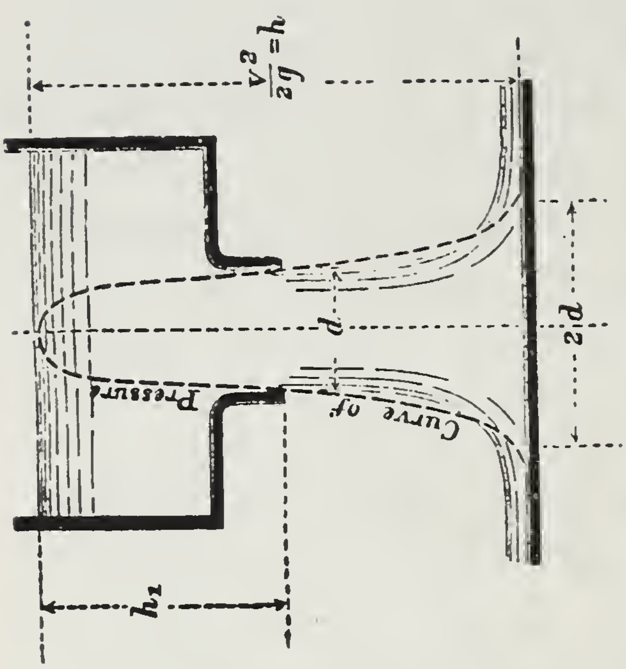
This reduces to 0.0 000 188 for 77 deg. Fahr., which is nearly ten times the value given by the Encyclopædia. Another error occurs on p. 77, near the top, equation (4). The last sign in the right member should be a minus sign instead of a plus sign. The correct equation is

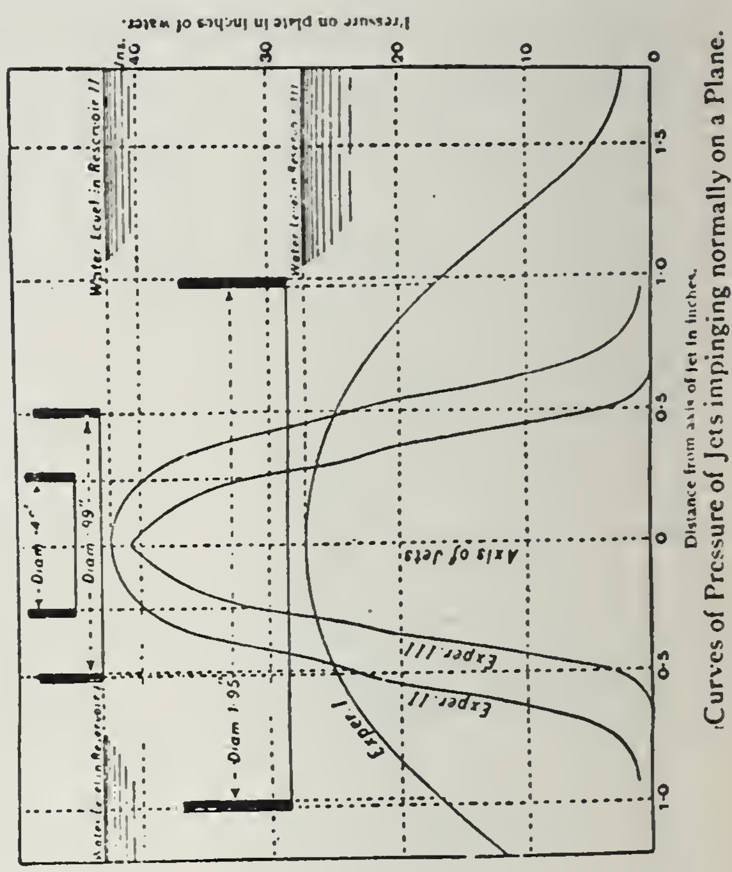
$$H^1 = \sqrt{(2U_0^2 H_0 \div g + \tfrac{1}{4} H_0^2)} - \tfrac{1}{2} H_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The error in the coefficient of viscosity was carried forward from the Ninth Edition of the Encyclopædia Britannica, and was noted by the writer in a paper on "Backwater", in the Minnesota Engineer (1909), University of Minnesota.

Messrs. White and Beresford can only add to the value of their work.

Beresford's experiments were made primarily for the purpose of determining the pressure generated by water falling over a weir. It was claimed by several persons that water falling over a weir might generate pressures amounting to several times that due to the total fall of the water, whereas, Beresford claimed that such pressures could not exceed the pressure due to the velocity-head of the impinging water. He states the re-





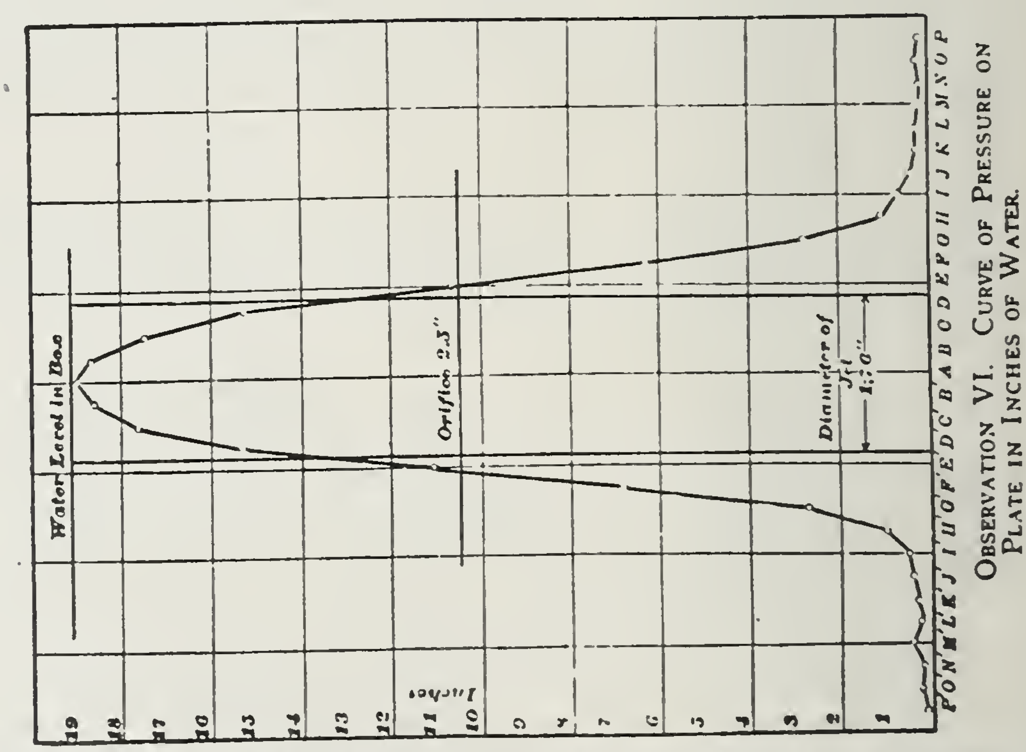


Fig. 2. Distribution of Pressure Over the Surface of a Plate upon which a Jet Impinges Perpendicular.

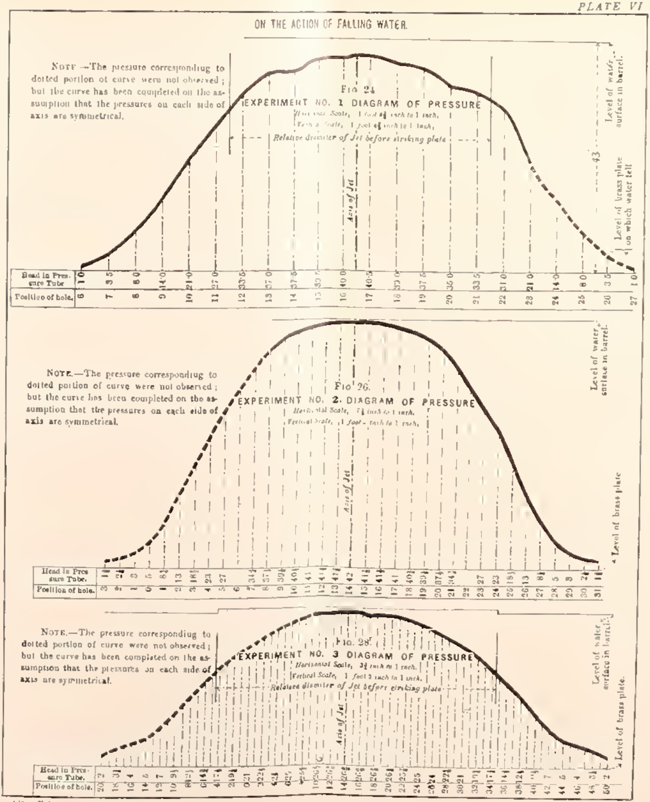


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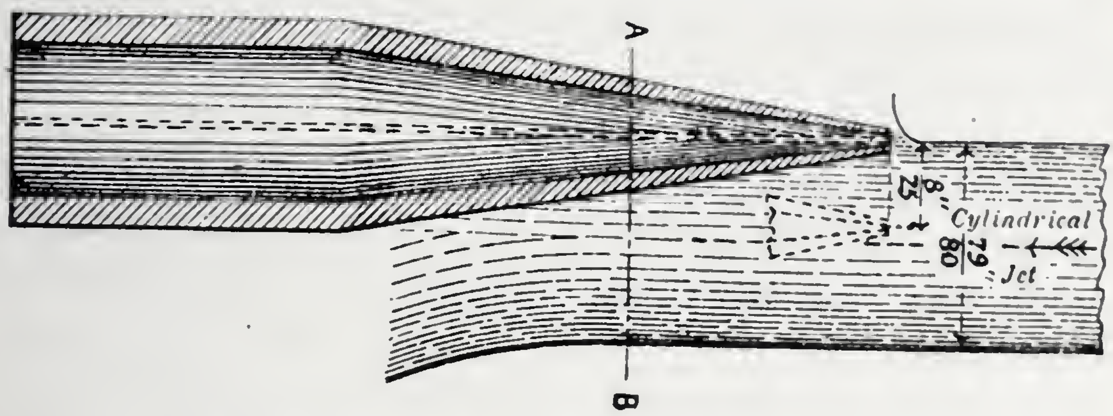
Fig 2-A Beresford's Original Curves.

sult of his experiments to determine the distribution of pressure of a jet of water impinging normally upon a flat plate in the following momentous language: "The important point to notice is that *in no case did the intensity of pressure reach that due to a column of water of a height equal to the head of water in the barrel,* or, in *other words,* to that of a *height due to the velocity,* but that in some cases it approached this limit to within one-sixteenth of an inch, so that had interfering causes been entirely removed, the surface of the water in the two glass tubes would have been on the same level for axial positions of the plate."

It should here be observed that the important point to be noticed, for the purpose of the present discussion, is not that expressed in italics above but that stated in the remainder of the paragraph. The smallest head experimented with was about 26 inches. Hence, it may be concluded that the maximum pressures obtained were within a very small fraction of one percent of the total fall.



EXPERIMENT No. 8—*Fig.* 33.

Position of nozzle as indicated by scale.	Head in barrel.	Head in pressure tube.	REMARKS.
*14	37 9/16	34	* The above diagram shows in section the position of nozzle corresponding to No. 14 on scale.
14 1/2	"	37 3/8	
15	"	37 1/2	
16	"	37 1/2	
17	"	37 1/2	*Note.*—The nozzle was moved from A towards B by 1/10 of an inch at a time, the axis of nozzle traversing a plane through axis of jet.
18	"	37 1/2	
19	"	37 1/2	
20	"	37 1/2	
21	"	37 1/2	
†22	"	37 1/2	† The dotted line shows nozzle in the position corresponding to No. 22 on scale.

Fig. 2-B. Early Investigation of the Distribution of Velocities in a Jet by Means of the Pitot Tube by Beresford, 1878.

It is also worthy of note that Beresford experimented with a Pitot tube upon the distribution of velocity across the diameter of a jet of water and found, what has since been verified many times, that the velocity indicated by the Pitot tube is almost absolutely uniform across the section and practically equal to $\sqrt{2gh}$ as the following table, (Fig. 2b) taken from his results, shows:

It may be explained that the nozzle was, in reality, a Pitot tube with its axis parallel to the axis of the jet. It was moved from the surface of the jet on one side toward the axis by one-twentieth inch at a time, the axis of nozzle traversing a plane through the axis of the jet. Excepting the water near the surface of the jet the experiments show that its velocity everywhere throughout the jet was that due to a head only one-sixteenth of an inch less than the head in the barrel, which was $37\frac{9}{16}$ inches. This experiment also proved that the coefficient of the nozzle, or Pitot tube, was practically unity.

An interesting incident occurred during the progress of the experiments which serves well to illustrate the necessity for the caution which must be exercised by experimentalists when interpreting their observations. When Beresford made his first observations upon the manometer tube receiving pressure-head from the hole in the plate upon which the jet impinged the water was seen to jump frequently to a height considerably above the level of the water in the tank. This was contrary to his expectations and he was led thereby to make an investigation which showed that it was caused by air entrapped in the water. Thus the manometer column, instead of indicating a head greater than the total fall, actually indicated a *smaller* one. Upon modifying the apparatus the difficulty was entirely removed.

It will be well worth the time and trouble for any hydraulic engineer to obtain and read Beresford's paper with the accompanying correspondence, especially the letter by Professor Unwin.† It will suffice here to say that Beresford had formulated his rule for estimating the pressure which would be exerted upon the apron of a weir by falling water before he made his experiments and he further recognized the fact that the great

†A copy of this paper is contained in the Boston Public Library, Boston, Mass.

danger was to be expected from pressure underneath causing "blow-outs" rather than from pressure *upon* the apron, or floor.

The foregoing statement is supported by the following "Note by J. S. Beresford, Esq., Executive Engineer, on the proposed weir at Keroni, on the Ken River, dated 13th April, 1877."

"From the foregoing my idea is, *that the greatest effect of falling water on any part of a floor is a simple pressure which can never exceed, in intensity, the pressure of a column of water of a height equal to the height due to the velocity of the water at the moment it touches the floor, and that this pressure is liable to be exerted in all directions.*"

Professor Unwin concurs in these views and gives some theoretical basis for them.

DESIGN OF DAMS

The foregoing remarks concerning the pressure at the toe of a dam generated by falling water have a very important bearing upon the design of spillway dams. If such pressures may be generated upon the apron, or floor, of a dam, and they

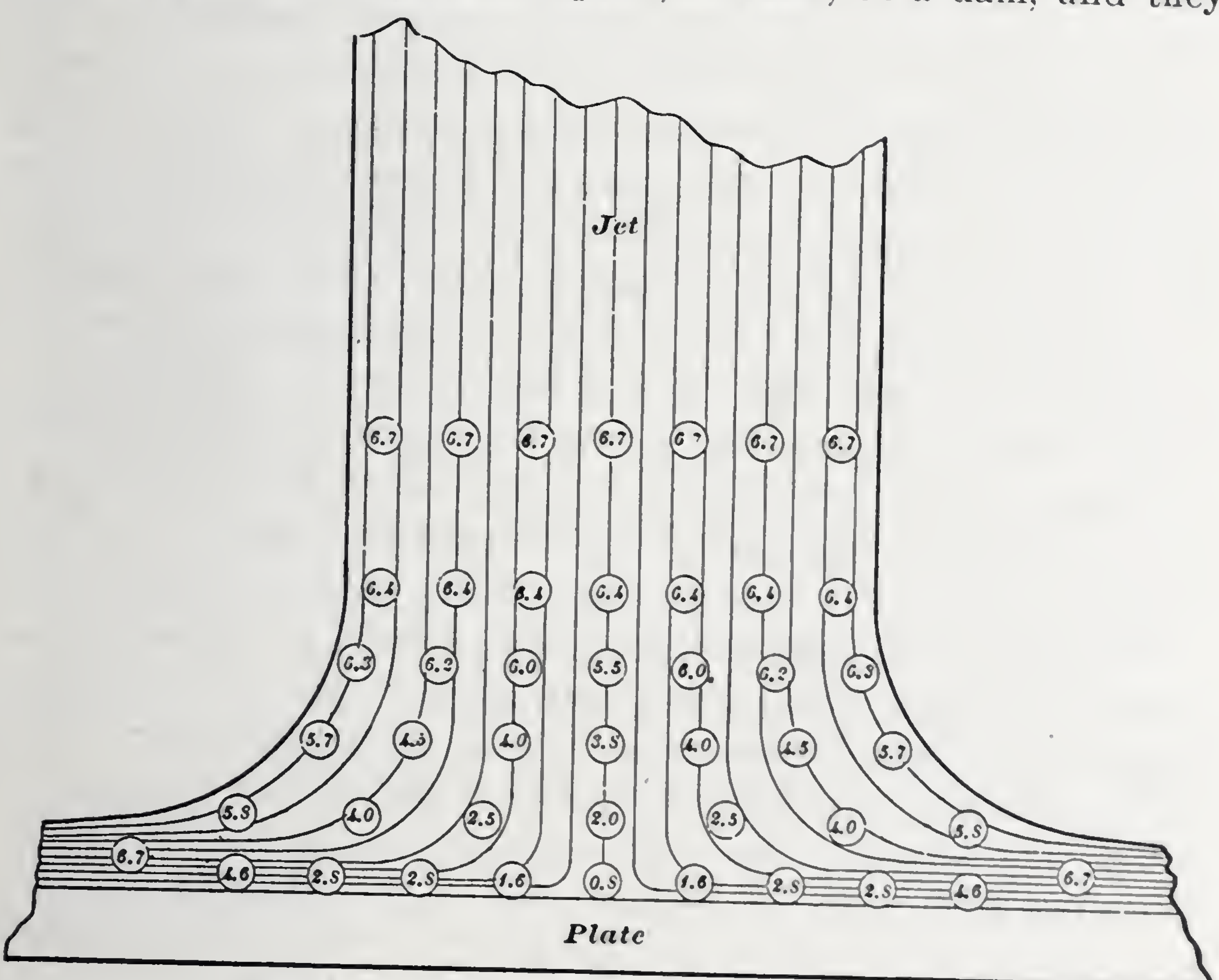


Fig. 3. White's Study of Stream-Lines.

are transmitted in all directions, it follows that, under certain conditions the toe of a dam may be subjected to a pressure due to the total hydrostatic head upon the upstream face when there is a discharge over the spillway sufficient to develop approximately the total theoretic velocity due to the head of water acting upon the structure. It is clear that the heel of the dam is subjected to a pressure due to the total head upon the upstream face. Therefore, under the conditions supposed, the entire base of the dam may have to sustain a pressure equal to that due to the total head upon the base reckoned from the elevation of the water surface in the pond above the dam. Under certain conditions it would also follow that the same rule will apply to any horizontal plane of the dam.

Figure 3 gives the results of a most interesting and instructive experiment by Mr. White (see p. 23 of the paper previously cited). In this experiment a 2-inch jet was allowed to impinge upon a large flat glass plate. A thin stream of colored solution was introduced at various points in the cross-section of the jet. From each of these points a small colored line could be plainly traced, thus locating a stream-line. The courses of these lines are shown in the figure and they prove conclusively that there is no cone of quiescent water resting against the plate. It has been maintained by some writers that there is such a cone at the dynamic opening of a Pitot tube. The numbers in the small circles give the velocities at the corresponding points of the jet. They were obtained by means of a very small Pitot tube. Mr. White makes the significant remark: "The point readings of the Pitot tube (referring to these experiments) always remain near the water level in the box, the static part of the tube varying as the velocities. In other words, the sum of the static and velocity heads is always equal to the distance through which the water falls." It is quite reasonable, therefore, to conclude that there is no cone of quiescent water in advance of the dynamic opening of a Pitot tube. This is also a conclusion of hydrodynamic theory.

SIMPLE PROOF OF THE PITOT TUBE FORMULA

In Fig. 4 let *mnpq* represent the extremity of the dynamic leg of a Pitot tube. Let *ab* be a small cylinder whose axis

is coincident with the axis of the horizontal part of the tube, which, in turn, has its axis parallel to the direction of flow. It will be assumed, for simplicity, that the water at *b* is at rest. If the tube is not improperly designed, and not too large, there will be such a point, even if it becomes necessary to consider the point *b* as being at the surface of the water column in the tube. In such a case it would not be necessary to take into account the static pressure at the opening for the purpose of computing

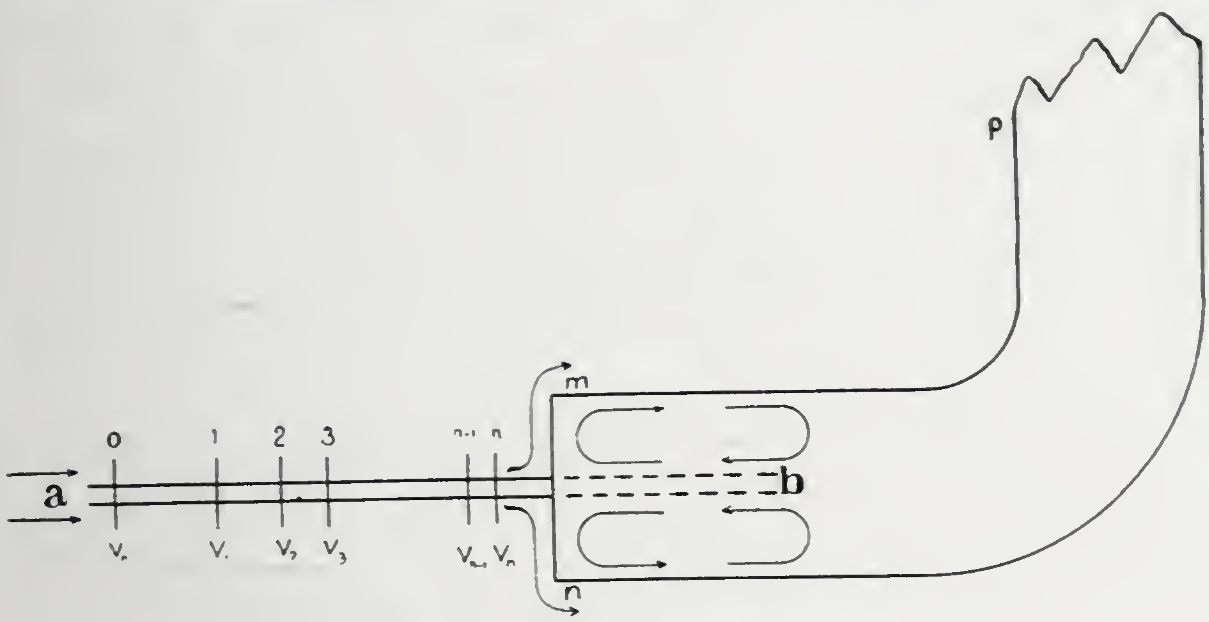


Fig. 4. Pitot Tube Reaction.

the impulse of the water and it is accordingly neglected. It is supposed that the flow is steady and that the water acts as a perfect, incompressible fluid. Therefore it will be possible to select points *0, 1, 2, - - - n,* along the cylinder such that all pairs of consecutive velocities differ by a given amount, which we may represent by the constant Δv. Generally these points will not be equidistant. Formula (1), of Fig. 1, may now be applied to find the sum of the forces which retard the *elements* of water between each pair of consecutive velocities, or consecutive sections, but with this difference; whereas, in applying formula (1) to the jet in Fig. 1, all the water which passes *0* also passes *n,* in applying the same formula to the elements of Fig. 4, no two of the cross-sections *0, 1, 2, - - n,* may be discharging the same quantity of water. Since we are concerned only with the pressure directed toward or away from the tube along the axis, *ab,* it is not necessary to consider transverse action, though this might easily be done.

By Formula 1[3],

$$\frac{wA}{g} v_o (v_o - v_1) > \Delta P_1 > \frac{wA}{g} v_1 (v_o - v_1) \ldots\ldots\ldots (5)$$

where ΔP_1 is the force retarding the water between *0* and *1*, within our cylinder, *ab*.

This inequality arises from the fact that the quantities of water passing the points *0* and *1* are not the same. In short, if there is retardation then water has escaped through the sides of our cylinder, but if there is acceleration water has passed into our cylinder from without. Only the former case is symbolized here. It will appear presently that this does not invalidate the final conclusion. In any case, the value of ΔP_1 lies between the values on the right and left in (5).

Now on the left we may make the following reductions:

$$\begin{aligned} v_o (v_o - v_1) &= v_o^2 - v_o v_1 \\ &= \tfrac{1}{2} v_o^2 + \tfrac{1}{2} v_o^2 - v_o v_1 + \tfrac{1}{2} v_1^2 - \tfrac{1}{2} v_1^2 \\ &= \tfrac{1}{2} v_o^2 + \tfrac{1}{2} (v_o - v_1)^2 - \tfrac{1}{2} v_1^2 \\ &= \tfrac{1}{2} v_o^2 - \tfrac{1}{2} v_1^2 + \frac{\Delta v^2}{2} \end{aligned}$$

and by similar process on the right the following:

$$v_o v_1 - v_1^2 = \tfrac{1}{2} v_o^2 - \tfrac{1}{2} v_1^2 - \frac{\Delta v^2}{2}$$

whence inequality (5) becomes

$$\frac{wA}{g} \left\{ \tfrac{1}{2} v_o^2 - \tfrac{1}{2} v_1^2 + \frac{\Delta v^2}{2} \right\} > \Delta P_1 > \frac{wA}{g} \left\{ \tfrac{1}{2} v_o - \tfrac{1}{2} v_1^2 - \frac{\Delta v^2}{2} \right\} \quad (6)$$

By analogy, for the retarding force between 1 and 2, Fig. 4,

$$\frac{wA}{g} \left\{ \tfrac{1}{2} v_1^2 - \tfrac{1}{2} v_2^2 + \frac{\Delta v^2}{2} \right\} > \Delta P_2 > \frac{wA}{g} \left\{ \tfrac{1}{2} v_1^2 - \tfrac{1}{2} v_2^2 - \frac{\Delta v^2}{2} \right\}. \quad (7)$$

Finally for the last space from *n — 1* to *N*

$$\frac{wA}{g} \left\{ \tfrac{1}{2} v_{n-1}^2 - \tfrac{1}{2} v_n^2 + \frac{\Delta v^2}{2} \right\} > \Delta P_n > \frac{wA}{g} \left\{ \tfrac{1}{2} v_{n-1}^2 - \tfrac{1}{2} v_n^2 - \frac{\Delta v^2}{2} \right\}. \quad (8)$$

If all the inequalities like (6), (7) and (8) be added, so as to get the sum of all the elementary forces acting upon the cylinder, *ab*, Fig. 1, noticing that the second term within any brace cancels the first within the next lower brace, the

[3] The potential is omitted here for the sake of simplicity since its introduction would not affect the final conclusion.

following inequality results, there being n terms in the summation:

$$\frac{wA}{g}\left\{\tfrac{1}{2}v_o^2 - \tfrac{1}{2}\,v_n + \frac{n\Delta v}{2}\Delta v\right\} > P > \frac{wA}{g}\left\{\tfrac{1}{2}v_o^2 - \tfrac{1}{2}\,v_n^2 - \frac{n\Delta v}{2}\Delta v\right\} \ldots (9)$$

Here P is the total change in pressure between the points 0 and N, both being arbitrarily taken. Further more $n\Delta v$ is equal to $v_o - v_n$[4], since there were supposed n terms of the sum and Δv is the constant difference between consecutive velocities.

Therefore,

$$\frac{wA}{g}\left(\frac{v_o^2 - v_n^2}{2} + \frac{v_o - v_n}{2}\Delta v\right) > P > \frac{wA}{g}\left(\frac{v_o^2 \; v_n^2}{2} - \frac{v_o - v_n}{2}\Delta v\right) \ldots (10)$$

Now if n be taken sufficiently large, or what is the same, if Δv be taken sufficiently small, the extreme right and left of (10) may be made to differ from each other by a quantity as small as you please. It follows *a fortiori* that either side will differ as little as you please from the value of P. Therefore, the limit, when $\Delta v = 0$, of either the right or left hand member of (10) is equal to P. Therefore,

$$P = wA\,\frac{v_o^2 - v_n^2}{2g} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$ [5]

This equation, (11), then, is the formula for the change in pressure, P, between any two points of the cylinder, where the velocities are v_o and v_n. Moreover, these points are arbitrary and may be taken at pleasure.

A most important conclusion follows from this result:

The change in pressure depends in no measure upon the manner in which the velocity changes from point to point, but only upon the initial and final values of the velocity.

Therefore take the point 0 sufficiently far from the tube so that the flow is practically parallel at the point selected. This is somewhat indefinite, but practically it cannot be far

[4]Note that $n\Delta v$ may be less than $v_o - v_n$ where pressures alternately rise and fall. However this does not affect the inequality for the case at hand.

[5]In the notation of the infinitesimal calculus the operations would be indicated more briefly thus:

$$P = \frac{wA}{g}\int_{v_n}^{v_o} v\,dv = wA\,\frac{v_o^2 - v_n^2}{2g}$$

from the mouth of the tube. Take the point n back to the point b in the tube or further if necessary, to a point where it may be safe to conclude that the water is at rest. This, too, is indefinite, but practically the water must be at rest somewhere in the tube. In short, it will not be a Pitot tube if it is made so large or of such a shape that the water moves within it to any great extent. When this point is reached $v_n = 0$ and we have

$$P = wA \frac{v_o^2}{2g} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

What we have done now is to sum up all the pressure increments along our little cylinder of area, A, and this reaction is pressure and it is distributed over the area A and is therefore capable of supporting a head

$$h = \frac{P}{wA} = \frac{v_o^2}{2g} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Now it is true that the pressure may not be uniform over the cross section of a cylinder of area A at any one intermediate point, but if we start with a section 0, and end with a section b, where the velocities are respectively v_o and 0, then, *since the total reaction along each infinitestimal cylinder depends only upon the initial and final values of the velocity and not upon intermediate velocity gradients, we must conclude that the pressure head over a finite area at some point within the Pitot tube is practically uniform and equal to* $v_o^2 \div 2g$.[6] It further follows that our cylinder may be of a diameter equal to that of the Pitot tube while the resulting pressure is uniform over the entire cross-section at the point where the velocity is zero.

MOTION WITHIN A PITOT TUBE

Referring again to Fig. 4, it is very probable that the motion indicated by the arrows actually takes place within a Pitot tube. This would naturally follow from the fact that the water must approach the mouth of the tube and flow away therefrom in a manner similar to that which occurs when a jet

[6]The validity of this formula for a Pitot tube in air has been demonstrated most beautifully by Professors Greene and Moody at Rensselaer Polytechnic Institute. See also a paper by Rowse, Jour. of the Am. Soc. M. E., September, 1913.

impinges upon a plate, as in Fig. 1. There is no "dead water" ahead of the plate or tube but the central stream-line must reach a point of very slow motion near the mouth of the tube. The current there divides and flows outward on all sides. This would tend, by reason of viscosity, to set up the motion indicated. It will be observed, as already stated, that this *intermediate* motion will have no effect upon the head raised, provided there is a region still farther back in the tube where the velocity is practically zero.

COMPARISON OF FORMULAS

$$h_1 = v_o^2 \div g \qquad (4)$$

$$h = v_o^2 \div 2g \qquad (13)$$

Formula (4) represents the ideal average pressure-head that would have to be exerted upon an area equal to the cross-sectional area of a jet of water in order to generate a total pressure sufficient to kill the original component of velocity of *all* the water issuing from the orifice. It is derived from Formula 1 by making $v_n = 0$, and dividing the result by wA. In formula (1), v_n is the remnant of the original component of velocity.

Since formula (1) represents the change in pressure necessary to change the velocity of a quantity, Av_o, of water from v_o to v_n, it may be employed, with more or less approximation, to ascertain the rise of pressure between any two consecutive sections, as in Fig. 4, by letting A represent the area of the section (herein taken as constant) while v_o represents the entering velocity and v_n the discharging velocity as the water leaves the element of space considered. The degree of approximation will be greater as the size of the element is taken shorter, since, in the case under consideration, the quantity of water actually retarded is less than Av_o and greater than Av_n. It is understood that the subscript n may have the values *1*, *2*, *3*, etc, and the size of the elements may be as small as desired.

Thus understanding formula (1), it may be employed to sum the forces acting upon the elements of water forming the cylinder in Figure 4. When these elements are taken sufficient-

ly small the sum is found to approach a limit indicated by formula (11). This limit leads at once to formula (13) as given.

EFFECT OF FORM

In the proof of equation (13) and the intermediate steps it was seen that the head, h, does not depend upon the manner, or suddenness, with which the velocity changes take place, but only upon the initial and final values of the velocity, the final value being zero. This being the case, it will be seen that any form of Pitot tube which brings the water to rest will satisfy equation (13). The indispensable requirement is that the velocity be reduced to zero at, or within, the tube. It follows that the tube may be of any size or shape but to insure the suppression of motions the tube leading to the manometer may be diminished as much as practicable.

Hence, we find that tubes of various sizes and shapes, from the stylographic pen point employed by John R. Freeman[7] to the various sizes and shapes experimented with by W. M. White, as described in the paper cited above, all satisfy equation (13) with great fidelity.

THE STATIC OPENING

In order to be able to employ a Pitot tube it must be borne in mind that the static pressure as well as the dynamic is recorded by the Pitot tube. The head, h, raised by the impulse, or hydrodynamic action, will have superposed upon it the static pressure at the mouth of the tube. Consequently, there must be a second opening for practical use, an example of which may be seen in Fig. 10.

The difference between the heads in the dynamic and static openings is the head which appears in equation (13). If the static opening, for any reason, fails to indicate the true static head, then an error is introduced. This fact, and the great liability of the static reading to be erroneous, has caused most of the trouble which has been experienced with the Pitot tube.

This has been most clearly stated by W. C. Rowse in his paper "Pitot Tubes for Gas Measurement" in the September,

[7]Experiments Relating to Hydraulics of Fire Streams, Transactions, American Soc. of Civil Engineers, Vol. 21, page 303. (Awarded Norman Medal for 1890.)

1913 Journal of the American Society of Mechanical Engineers as follows:

"It has been satisfactorily proved and accepted that the dynamic tube gives the correct pressure if the tube points parallel to the current. But it is a very difficult matter to obtain the correct static pressure on account of secondary velocity effects. Therefore the study of the accuracy of the Pitot tube resolves itself into a study of the correct method of obtaining the static pressure at the given cross-section where the tube is inserted."

His conclusion *d*, page 1341 is also of exceeding importance to Pitot tube designers. He writes:

"Of the methods of obtaining the static pressure by the Pitot tube itself, the most reliable and accurate is by means of a very small hole in a perfectly smooth surface, as in Pitot tube "Y".

REACTION OF A JET

Figure 5 represents a beautiful experiment given by Unwin in his article on hydraulics in The Encyclopædia Britannica, previously referred to. Two tanks provided with equal converging mouthpieces are placed so that the axes of symmetry of the opposing converging pipes are coincident. If water be supplied to *A* sufficient to maintain the level shown, then the

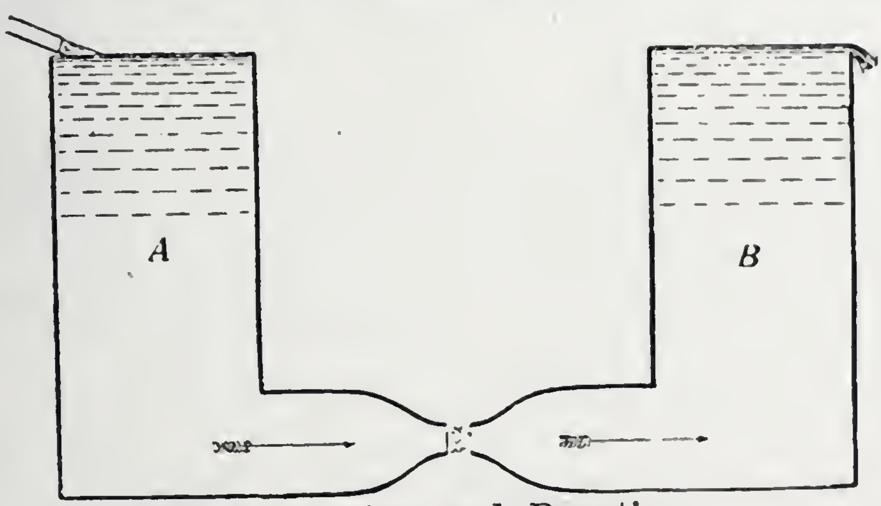


Fig. 5. Action and Reaction.

jet from *A* is capable of shooting across the space between the two vessels without any serious loss and supporting a head in *B* nearly equal to that in *A*. In the particular experiment mentioned there were 20½ inches of head in *A* and 18 inches in *B*. We may now infer, from what has preceded, that if a light flat

plate were placed over the mouth of *B* while the jet from *A* was allowed to impinge upon it, the pressure of the jet upon the plate would be sufficient to support a head in *B* of nearly 40 inches, but that, if a small hole were bored through the plate, concentric with the axis of the jet, the head in *B* would not exceed that in *A*, 20½ inches.

It must not be supposed, however, that the intensity of pressure is any greater in one case than in the other. In fact our theory demands that it be practically the same in the two cases and this it has been shown is verified by experiment. It is true that the reaction of the jet upon *A* is equal to the action of the jet upon the plate against the mouth of *B*, which action is capable of supporting a double head in *B* as compared with the head when the plate is removed. But we have no right for this reason to assume that the action upon *B*, when the plate is removed, is any less than the reaction upon *A*. Indeed, they must be the same. And the reason therefor is that as the water approaches the orifice along the walls of *A*, or recedes from the orifice along the walls of *B*, the pressure upon the walls of the vessels varies according to the theorem of Bernoulli. Since the velocity is the higher the nearer the orifices, the pressure is correspondingly lower, and this leaves an excess of pressure on the walls of the vessels opposite the orifices which gives rise to the reaction upon *A* and to the equal action upon *B*‡.

It is interesting to observe that the chances that the stream-lines in *A* are similar in form to those corresponding in *B* are very slight. In fact very little consideration will lead to a strong conviction that such is not the case. But this does not negate the equality of the action and reaction upon *A* and *B*, for the total change of momentum is precisely the same in the two cases, save for the small losses due to friction and leakage, and this whatever the form of the system of stream-lines.

‡In explaining these phenomena, at least one authority states that "Where the water overflows from *B*, the impulse of the jet has not only to overcome the static pressure, due to the head *h*, but also to furnish the dynamic pressure equivalent to a second head *h*, in order to raise the water through that height.

It would appear from this that $h = v^2 \div g$, which is certainly incorrect. (See Merriman's Hydraulics, 1904, p. 380.)

STANDING WAVE

Standing waves afford another interesting illustration of the operation of hydrodynamic forces. When water falls over a weir or dam there is formed at the foot of the spillway, or removed therefrom to a greater or less distance, a stationary wave

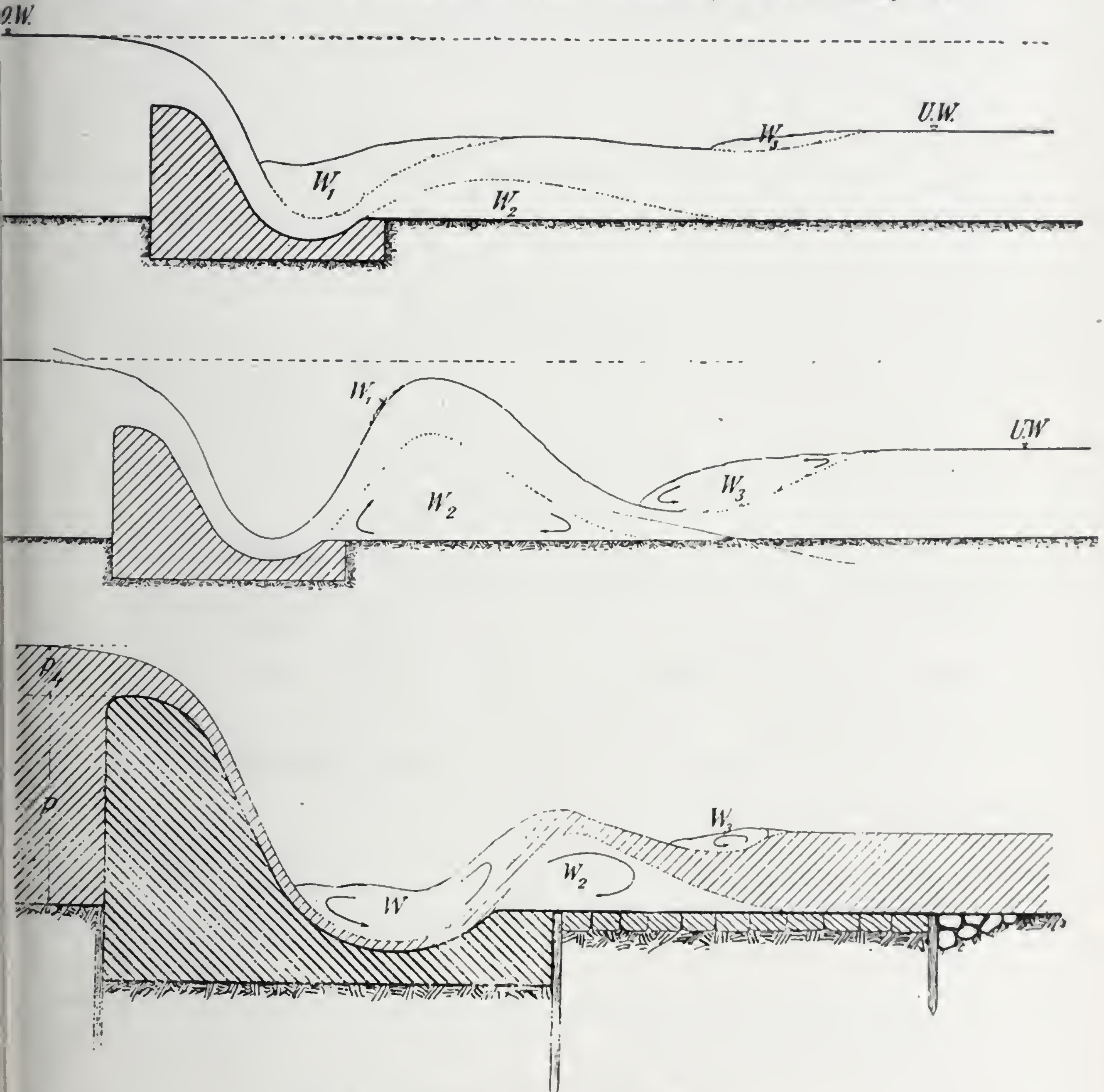


Fig. 6. Pulsating Standing Wave.

which rises to a greater or less height according to circumstances. The rise is effected at the expense of velocity. Figure 6 shows such waves as illustrated in the Handbuch der Ingenieur-Wissenschaften, part 3 (Wasserbau), II Band, 1 Abteilung, 4 Auflage, pp. 46 and 47. Several formulas have been proposed for computing the height of such waves but it is not likely

that any formula can be very reliable which does not take into account the character of the spillway and channel. It would further seem that *time* should, under certain circumstances, be introduced, for there is a certain class of standing wave which pulsates, or varies in form, according to some periodic function of the time. According to the Handbuch, if the discharge rises considerably above that shown relatively in the first figure to a certain amount as shown relatively in the second figure then the water in the *roller*, W_1, will be gradually scoured out by the stream beneath, which latter will then rise greatly over the roller, W_2, which also rises and enlarges, so as to form a great standing wave with steep slopes as shown in the second figure. The wave finally breaks over itself toward the weir in consequence of the steadily increasing steepness of its up-stream slope. This causes the roller, W_1, to form again as shown in the third figure after which the roller is scoured out as before while the conditions gradually return to those illustrated in the second figure. Thus we have a pulsating wave.

In the case of a model weir 18 cm. high with 10.5 cm. fall and 14.5 cm. tail-water-depth the period of pulsation was 9.5 sec. With a 22 cm. weir the period was 12 sec. With only slight changes of head water or tail water the phenomenon vanished and the high wave did not form.

Similar phenomena for certain discharges have been observed at some actually constructed weirs.

The methods of deriving these imperfect formulas, however, are extremely interesting and are of value in fixing upon the mind some of the principles involved in the Pitot tube reaction.

The following treatment of the standing wave is substantially that given by Unwin in the treatise on Hydraulics mentioned above:

Let w = the weight of a cubic unit of water;
g = the acceleration of gravity;
q = the discharge of a unit of width of the stream;
h_1 = the depth of water at a section of the stream just up-stream from the point where the standing wave begins to rise. For simplicity the bottom is supposed level;

v_1 = the velocity at the above mentioned section;
h_2 and v_2 represent respectively, the depth and velocity in the section at the point where the wave attains its maximum height.

The basis of the solution then is to place the change of momentum per second between the two sections equal to the total retarding force due to the difference of elevation existing between the water surfaces at the two sections which, for simplicity, we have taken of unit width. The rate of change of momentum is

$$\frac{wqv_1}{g} - \frac{wqv_2}{g}$$

and the total difference in pressure between the two sections is

$$\tfrac{1}{2}w(h_2^2 - h_1^2)$$

We have also the equation of continuity $q = h_1 v_1 = h_2 v_2$, which serves to eliminate v_2. Solving the resulting equation we may obtain

$$h_2 = \sqrt{(2v_1^2 h_1 \div g + \tfrac{1}{4}h_1^2)} - \tfrac{1}{2}h_1 \ldots\ldots\ldots\ldots (14)$$

The rise of the standing wave then is $h_2 - h_1$.

The foregoing reasoning is undoubtedly sound so far as mathematical logic is concerned, but it involves an assumption at the outset which cannot be justified, namely that the retarding pressure is $\tfrac{1}{2}w(h_2^2 - h_1^2)$. If such an assumption be permissible in the case of the standing wave it ought to apply, with suitable adaptations, to other cases. Let us therefore apply the assumption to the case of the opposing orifices in Figure 5, but have the tank B extended to the right indefinitely, so as to make the case more plainly analagous to that of the wave. It evidently makes no difference how large the vessels may be.

Then all the equations employed in demonstrating equation 14, with slightly modified notation, apply. The head h_1 and the velocity v_2 become negligible. Thus the equations of condition may take the form:

change of momentum per second $= wqv_1 \div g = wa_1 v_1^2 \div g$;
total retarding pressure $= \tfrac{1}{2}wa_2 h_2$;

where a_1 is the area of the orifice in tank B and a_2 is the area

of the vertical transverse cross-section of the tank at some distance from the orifice.

Equating the two expressions just derived it is easy to show that

$$h_2 = \frac{4a_1}{a_2} \frac{v_1^2}{2g} \dots\dots\dots\dots\dots\dots\dots\dots\dots (14a)$$

But we know by experiment that, practically, $v_1^2 = 2gh_2$. Hence, it must follow that $a_2 = 4a_1$ in all cases. The absurdity of such a conclusion is obvious, and it proves that there are wrong assumptions entangled with the premises, as has been indicated. We do not mean to say, however, that a certain *ideal* a_2 may not be equal to $4a_1$.

Another discussion of this subject is given by Professor Merriman in his Treatise on Hydraulics. Adopting the notation just employed and putting $h_2 - h_1 = j$, the lost velocity-head will be

$$\frac{v_1^2 - v_2^2}{2g}$$

and this, according to Professor Merriman, is lost in two ways —first by the impact due to the expansion of section, and second by the uplifting of the whole quantity of water through the height $\frac{1}{2}(h_2 - h_1)$, loss in friction between h_1 and h_2 being neglected. The loss due to expansion of section is

$$\frac{(v_1 - v_2)^2}{2g}$$

and the continuity equation takes the form $v_2\ (h_1 + j) = v_1\ h_1$. By means of these relations v_2 may be eliminated and the resulting equation solved for

$$j = -h_1 + 2\sqrt{(h_1 v_1^2 \div 2g)} \dots\dots\dots\dots\dots\dots (15)$$

It is not clear to the writer why the second loss is caused by the uplifting of the whole quantity of water through the height $\frac{1}{2}j$. It would seem more reasonable to write the usual Bernoulli equation with a term for losses as in the case of friction losses in pipes. Thus the first equation of condition would be

$$\frac{v_1^2}{2g} + h_1 = \frac{v_2^2}{2g} + h_2 + L \ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

where L is the sum of the losses of head due to the various causes which are active. If L be taken equal to the loss due to expansion, as above, neglecting all other losses, it may be shown that

$$j = -h_1 + \sqrt{(h_1 v_1^2 \div g)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

The value of h_2 as determined by equation (15) is to its value as determined by equation (17) as the square-root of 2 is to unity. Thus equation (17) gives a smaller value of h_2 than equation (15) and this is due to the fact that equation (15) would become identical with equation (17) if the second loss considered in equation (15) were taken equal to j *instead of* $\frac{1}{2}j$. In short it is inconsistent to write $\frac{1}{2}j$ for the second loss in equation (15) if Bernoulli's equation is to be relied upon. Nevertheless, equation (15) in many cases, gives results only slightly in excess of observed values, whereas equation (17) frequently gives results considerably deficient in value. This would point to the probability that the loss due to expansion employed in the proof of equation (15) does not apply with sufficient accuracy to the case of the standing wave. It introduces too large a loss and this is more than neutralized by the error committed when the second loss of velocity-head is taken as equal to only half what it should be. Equation (16) containing L would give correct results if the value of L could be expressed in terms of the dimensions of the spillway and channel in which the wave occurs. In certain cases it should contain the time also, as explained above.

NATURAL PITOT TUBES

There are many places in rivers where velocity-head is transformed to potential-head with surprising fidelity to Bernoulli's theorem. A very favorable location for observing such phenomena is at the head of an island in the center of a swift channel. Figure 7 shows an interesting example. Here a velocity of 8.95 feet per second, flowing as indicated by the long curved arrows, piles the water up as it approaches the head of Delany Island in the St. Lawrence River, a short dist-

ance below Richard's Landing. At a distance of ¼ mile above the head of the island the water surface is at elevation 203.4 feet above sea level and moving in an almost perfectly straight line toward the head with the velocity given. At the head the water has come to a complete rest and its elevation has risen to 204.5. Thus 1.1 feet of the head, 1.25 feet, due to the velocity, 8.95 feet per second, has actually been conserved while the water was flowing a distance of ¼-mile over an irregular bed.

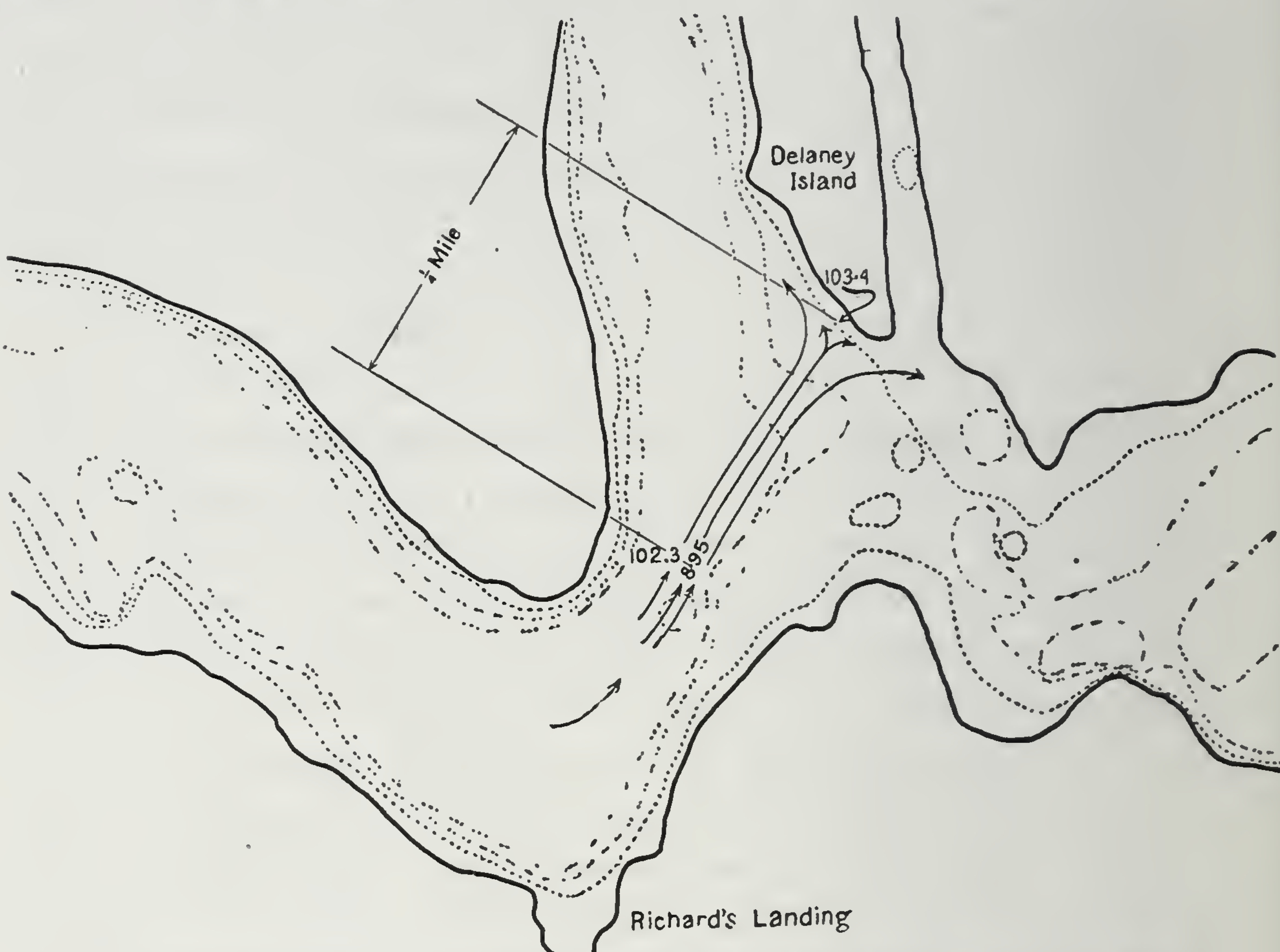


Fig. 7. Bernoulli's Theorem Applied to the St. Lawrence River.

This particular case of the phenomenon was first observed by John R. Freeman. Several years later the writer verified the velocities and elevations. The velocities were measured at the later date by means of floats about 4 feet deep, so that the surface velocity was that practically observed over the deeper parts of the channel where the velocity was considerable.

Now the velocity by this natural Pitot tube is $\sqrt{(2g \times 1.1)} =$ 8.42 feet per second while the actual velocity was 8.95 feet per second. Therefore the ratio of the Pitot tube velocity to the true velocity is $8.42 \div 8.95 = 0.94$. The coefficient of this natural Pitot tube is thus $8.95 \div 8.42 = 1.06$. That is to say, it is necessary merely to increase the velocity computed from

the observed rise of surface by 6 percent, a comparatively small correction for such a casual Pitot tube.

Here also we may learn that such eddies as occur in a short reach of swift current over an irregular bed have but little effect in vitiating Bernoulli's theorem. It matters little how the water is brought to rest; the tendency is for it to flow according to the theorem.

PITOT TUBE HEADS

It is important to compute the head indicated by a Pitot tube in a proper manner or an error of more or less moment is likely to result. It is to be observed that velocities are proportional to the square roots of corresponding heads and therefore the average head indicated by a Pitot tube in a variable current is proportional, not to the square root of the mean indicated head, but to the mean square root of the variable head. If several heads are read at successive instants then the square root of each is to be extracted and the mean of these roots taken as the mean square root of the variable head indicated at these instants. If the variable head is taken in the form of a continuous time-curve then another curve is to be drawn whose ordinate is everywhere the square root of the corresponding ordinate of the original curve. The mean ordinate of the curve so constructed is the mean square root of the variable head indicated by the original curve. Some instruments may be so constructed as to draw the square root curve at once, in which case the mean ordinate so drawn would be the required mean square root without further reduction.

Two examples of the process described are given in Table

TABLE NO. 1.

METHOD OF COMPUTING AVERAGE HEAD ACTING ON PITOT TUBE.

(The readings are taken from actual observations.)

0.48	0.53	0.48	0.49
0.53	0.43	0.51	0.46
0.50	0.49	0.48	0.46
0.50	0.52	0.48	0.46
0.50	0.50	0.48	0.48
Square root of mean = 0.6986			
Mean square root = 0.6983			
0.16	0.19	0.24	0.21
0.24	0.26	0.23	0.31
0.24	0.14	0.23	0.22
0.19	0.30	0.32	0.28
0.26	0.28	0.13	0.22
Square root of mean = 0.4822			
Mean square root = 0.4790			

Note: Units in columns above are feet.

1. In the first part twenty heads whose mean square root is 0.6983 foot are shown. The comparison of this mean square root with the square root of the mean, 0.6986, is also shown. The error produced is only a small fraction of one percent. The readings, however, are unusually uniform for this class of work in ordinary channels. The second case exhibits considerably larger variations, relatively, and the error is, accordingly, more than six-tenths of one percent. However, the results show that the errors to be encountered with only fair conditions existing are not so large as might be anticipated.

Another fact may be inferred from these tables. It is that the means deduced from consecutive series of readings taken in variable velocities, reading only to the nearest hundredth of a foot, will give very consistent results. For example, in the second table the four mean square roots deduced from the four columns of five readings each are, respectively, 4.65, 4.79, 4.75, 4.96, the units being hundredths of a foot. Thus the velocities determined from series of five readings each from the given table are quite consistent, whereas velocities based upon single readings are worthless for the purpose of determining average values. Accordingly, velocities based upon twenty readings, or more, even where velocities are quite variable and heads are read only to the nearest hundredth of a foot, have been found to yield unexpectedly good results.

In the case of the first table the mean square roots corresponding to the four columns of readings are, respectively, 7.08, 7.02, 6.97, and 6.86. These may be considered very good. They show that the velocity was actually being retarded throughout the observations.

It may be of some interest to describe briefly the method of taking the foregoing readings. In the first place, let it be understood that the observations were not made as an experiment upon the Pitot tube. They were taken for the purpose of making an actual discharge measurement of the quantity of water passing through a turbine. Hence the conditions were far removed from those to be desired in the accurate testing of a Pitot tube in a laboratory. The dynamic and static columns were drawn up on a scale graduated to single tenths and half tenths of a foot and the differences in head were merely esti-

mated by the observer to the nearest hundredth of a foot. This may seem crude, but when it is considered that the water columns were both vibrating, sometimes violently, that twenty or thirty readings were taken for each velocity, and that all percentage errors are nearly split in two by the process of extracting the square root of the head, it will be seen that the method is probably as accurate as need be for the purpose at hand. Indeed, the results of the actual turbine tests seemed to justify this conclusion.[8]

RELATIVE PERFORMANCE OF CURRENT METERS AND PITOT TUBES

The foregoing remarks relative to the computation of the mean head indicated by a Pitot tube are pertinent to the case of a Pitot tube when operated in the tail race of a power house for the determination of the discharge. But the accuracy of discharge determinations based upon Pitot tube or current meter observations has been very seriously questioned by a large number of eminent engineers, especially when the observations must be made in irregular currents of variable velocity. That these doubts were well founded was most conclusively shown by the preliminary tests made by the writer upon a six-thousand horse power turbine. In view of the adverse opinions expressed by so many engineers it was decided to make the test with two different types of current meter, after which, if the meter tests did not agree, to check the meters by means of a Pitot tube.

Accordingly a new Haskell meter of the screw type and a new Price meter (large size) of the cup type were procured for the turbine tests. These meters were carefully rated from a boat and were found to be quite reliable in the ratings when conditions were favorable. It was observed, however, that the rate observations for the Haskell meter were much more consistent than those of the cup type. But this fact left us quite unprepared for the large constant difference in the discharge determinations when two simultaneous tests were made by means of the two types of meter. The cup meter showed a constant difference of nearly six percent in excess of the discharge

[8] The tests were made by the writer at Massena, N. Y., in the summer and fall of 1911.

by the Haskell meter, and it was found that there were places in the tail races where the percentage error was nearly three times that relative amount.

An investigation was instituted to determine the cause of the discrepancy with the interesting result that if the boat was rocked during the ratings the meters would change their rates of rotation according to the rule that the cup meter was always accelerated considerably while the screw meter was always retarded slightly. About the same time it was ascertained that similar results had been observed by Charles H. Miller, M. Am. Soc. C. E.[9]

It was hardly practicable to make an accurate quantitative determination of these deviations since it was not desired to make a scientific study of current meters but rather to find an instrument which could be relied upon to give accurate determinations of turbine discharge. However the studies were carried on sufficiently to develop two very important facts. These were:[10]

First: When the boat was rocked in about the same manner in two ratings, one upon the screw meter and the other upon the cup meter, the deviations of the screw meter were about one-seventh those of the cup meter on the side of deficiency, the deviations of the cup meter being on the side of excess.

Second: When the two meters were operated simultaneously in a tail race, taking readings of equal weight, in two different comparisons, for the same meter points, the ratio of the sum of the velocities by the Haskell meter to the sum by the Price meter was an almost perfect constant for the same discharge. This showed that either meter could be relied upon to give a constant record in the races under the same conditions. In other words, the meters had perfectly definite ratings in the races but these ratings were not the same as those determined from ratings in still water.

The formal comparison of the meters in the tail races is shown in Fig. 8. It will be found that practically all the

[9] See a discussion of a paper on current meter and weir discharge comparisions by Charles H. Miller, *Transactions*, Am. Soc. C. E., Vol. 47, 1902, p. 370. The paper is by Edward C. Murphy, M. Am. Soc. C. E.

[10] For a more detailed description of these studies see a paper on current meters by the writer in *Transactions*, Am. Soc. C. E., Vol. LXXVI, p. 819 (1913).

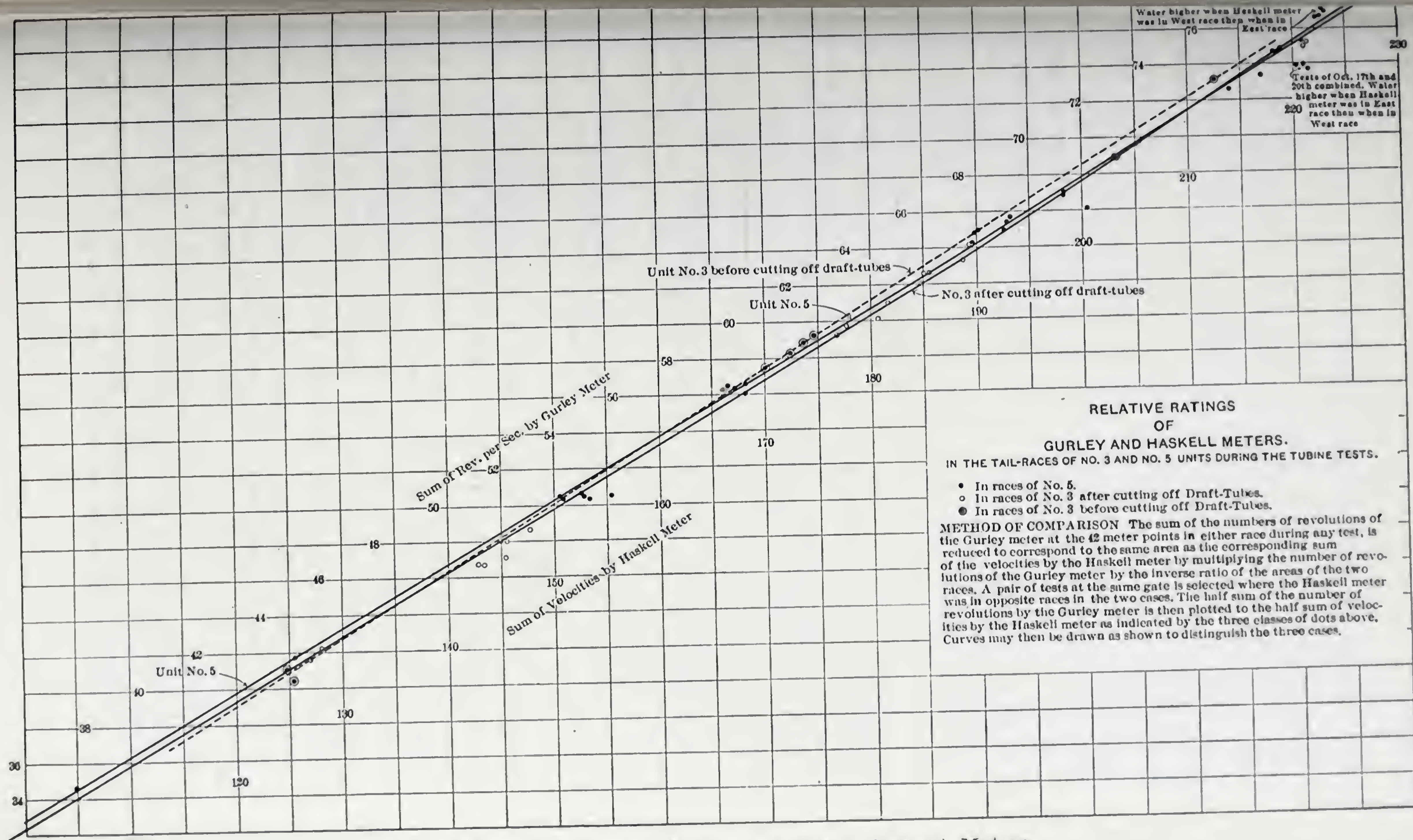


Fig. 8. Relative Readings of Cup and Screw Current Meters.

observations lie within a fraction of one percent of the finally established curves. The larger variations, too, were, for the most part, well accounted for by the small unavoidable variations of the circumstances of the individual tests which variations however, were not measured.

The two facts determined above supply a means of estimating the true velocity of a perturbed current by means of simultaneous observations with a cup meter and a screw meter. The two resulting velocities are determined from the still water ratings of the meters in the usual manner. In the case of the two particular meters in question one-seventh of the difference between the two velocities is added to the velocity by the Haskell meter which should give very closely the true velocity of the current. In this manner one may determine the true velocity at each of the meter points in a tail race and thus arrive finally at the discharge. This, in substance, was one method of determining the discharge in the tests by the writer at Massena. In addition the meters were rated in the races relative to the discharge as determined by a Pitot tube. With the results of the meter and Pitot tube observations, as outlined above, it is possible to determine the coefficient of the Pitot tube.

ACTUAL DETERMINATION OF THE COEFFICIENT OF THE PITOT TUBE IN THE TURBINE TESTS

Figure 9 shows a vertical, transverse cross-section of the twin tail races and the relative locations of the meter points at the 84 dots which are uniformly distributed over the sections. The contour lines are curves of equal velocity expressed as percentages of the sum of the velocities at the 42 meter points in each race. It will be noticed that the meter points in each race are at the intersections of six equidistant verticals with seven equidistant horizontals, thus locating 42 points—84 points in both races. The velocities are considerably higher near the bottoms than near the tops of the races and it may be explained that the flow was much more uniform near the bottoms than near the tops. In accordance with these facts the records of the meters were nearly identical, as to velocity, near the bottoms but diverged more and more as the meters were raised toward the upper and more agitated layers of water. It may be

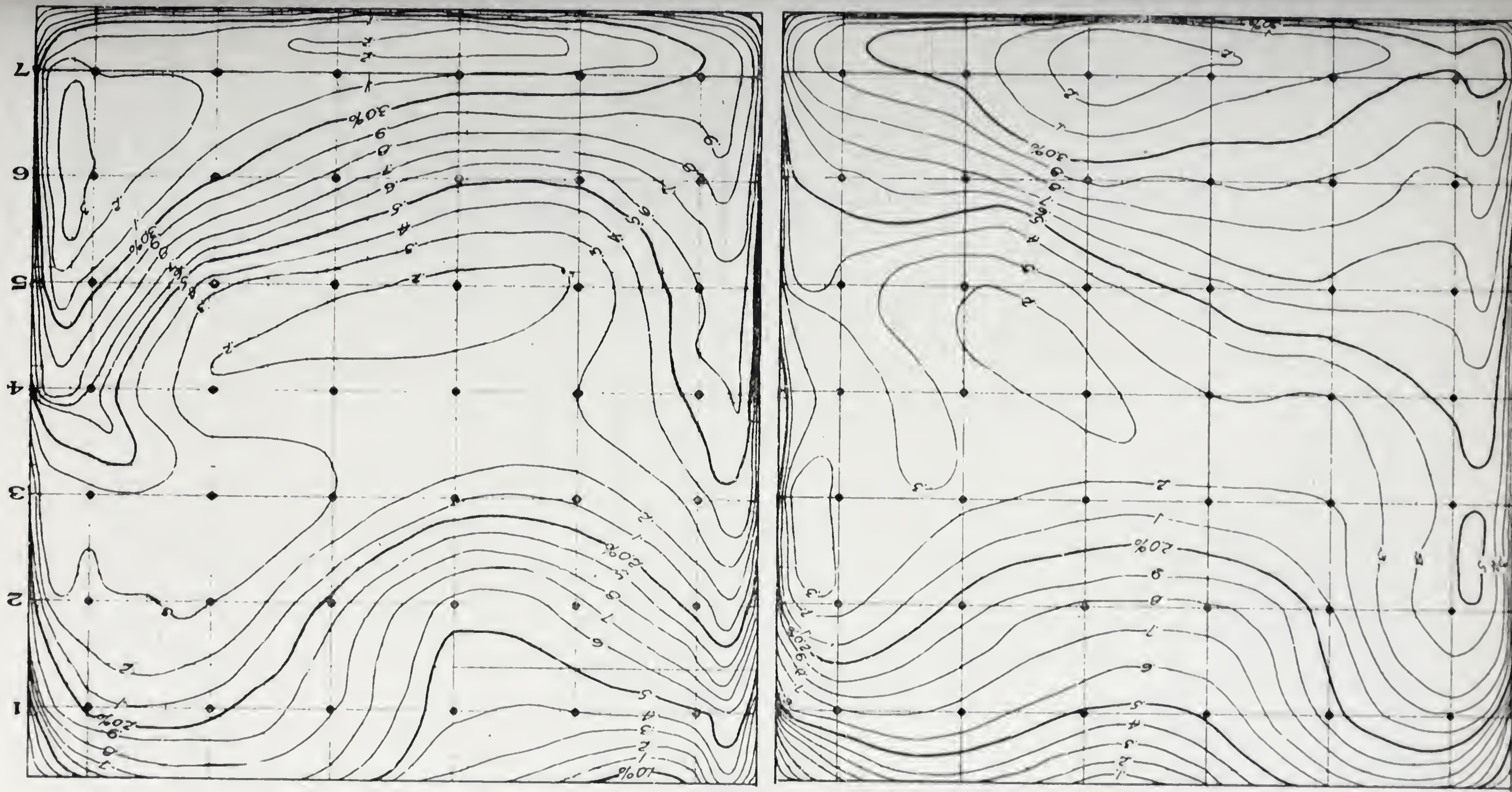


Fig. 9. Characteristic Curves of Equal Velocities in Tail Races.

of interest to state that the contours of equal velocity near the walls of the races were determined by means of a Pitot tube.

TABLE NO. 2.
COMPUTATION OF VELOCITY CORRECTIONS.

Horizontal in which meter was run.	Velocities Based on the Still-Water Ratings.		Difference.	One seventh of difference + Haskell = true velocity.	Velocity excessive by Gurley. Percentage.	Velocity deficient by Haskell. Percentage.
	Gurley.	Haskell.				
1........	3.94	3.36	0.58	3.44	14.5	2.4
2........	4.46	3.90	0.56	3.98	12.0	2.0
3........	4.74	4.44	0.30	4.48	5.8	0.96
4........	4.85	4.62	0.23	4.65	4.3	0.72
5........	5.08	4.89	0.19	4.92	3.2	0.55
6........	5.68	5.55	0.13	5.57	2.0	0.34
7........	6.32	6.15	0.17	6.17	2.3	0.38
Totals..	35.07	32.91	2.16	33.21		

$$\text{Average error of Gurley meter} = \frac{6}{7} \times \frac{2.16}{33.21} = 5.6 \text{ percent.}$$

$$\text{Average error of Haskell meter} = \frac{1}{7} \times \frac{2.16}{33.21} = 0.93 \text{ percent.}$$

Table No. 2 gives the computations of the velocity corrections for the two meters by the method described for the average velocity in each of the seven horizontals in which the meters were operated. The headings of the various columns are sufficiently explicit to make it clear to any one how the figures are derived. The first two columns, of course, contain simultaneous average velocities by the two meters. As a matter of fact, simultaneous velocities were not observed in the horizontals for the purpose of compiling the table. The velocities were computed from an elaborate series of percentages which have been better described in the paper on current meters previously referred to. Altogether, about 40 000 carefully correlated instrumental readings were taken in the complete series of turbine tests. With these figures it was possible to determine comparative (computed) simultaneous velocities for each of the 84 meter points in the races, and the figures of the first two columns of the table are averages for the seven horizontals taken from these simultaneous velocities.

Before deriving the coefficient of the Pitot tube employed in the experiments it will be interesting and instructive to know something about the form of the instrument. Figure 10 is a

sketch of the Pitot tube and the supporting pipe. The Pitot tube, to the right, is a form first investigated by W. M. White in the remarkable series of experiments already discussed. Mr. White's experiments showed that the coefficient of this tube is

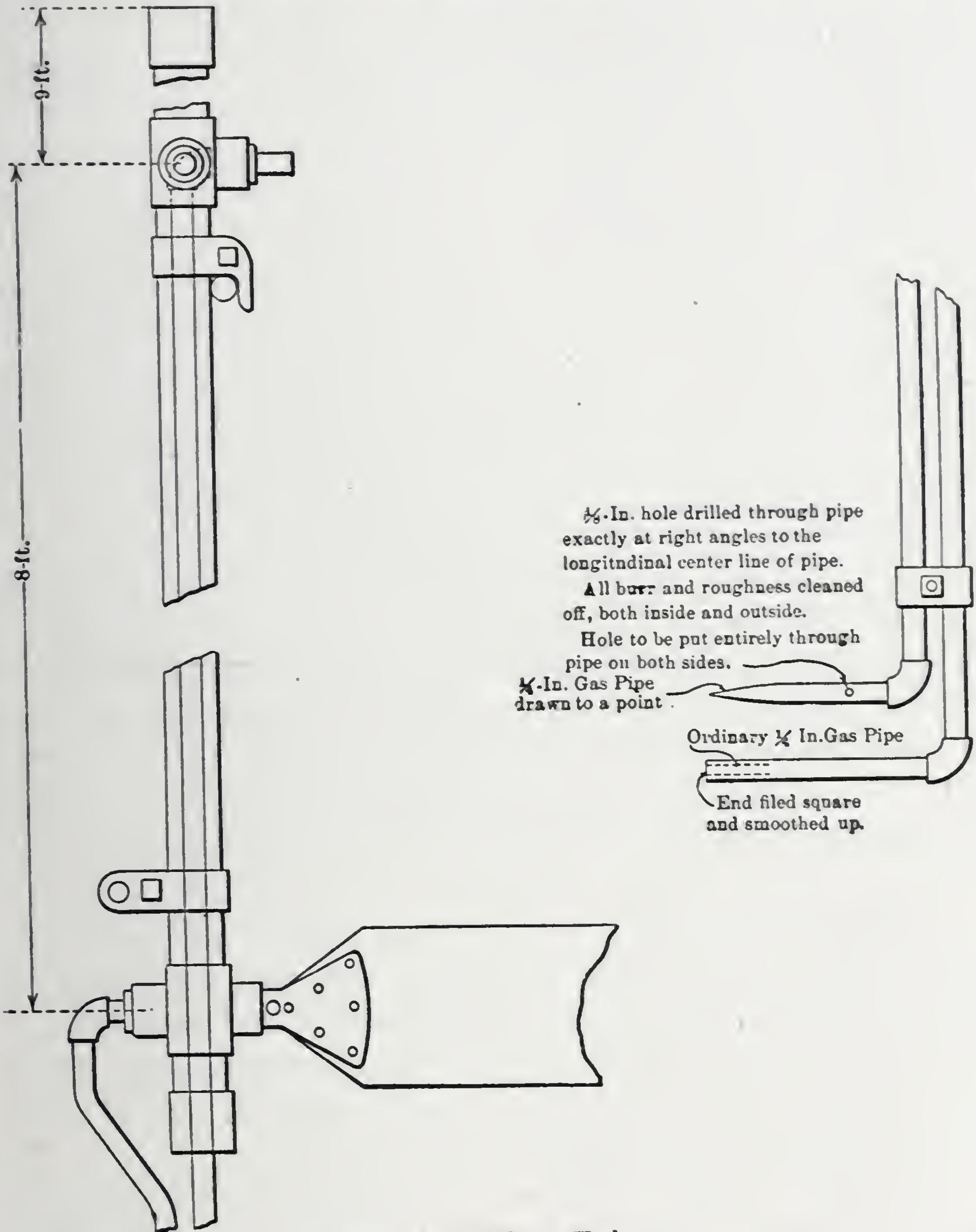


Fig. 10. Pitot Tube.

practically unity. This means that there is practically no error produced by the static orifice as located in the design of the instrument illustrated.

The supporting pipe, to the left in the illustration, was designed by the writer and the Pitot tube is attached to it by

means of couplings. The Pitot tube therefore can be easily removed when not in use. The support carries a number of hooks, one of which is shown in the sketch, for the purpose of transmitting the weight of the instrument to a horizontal rod which is maintained at a constant elevation during any series of experiments. By properly adjusting these hooks the instrument can be readily placed at any desired series of elevations by simply engaging the proper hook with the horizontal rod for each desired elevation. Further, by attaching rope clips to act as stops, or markers, along the horizontal rod the Pitot tube may be held in any desired series of verticals. Thus the intersections of the six verticals and seven horizontals are immediately located by means of seven hooks on the supporting pipe and six rope clips on the horizontal rod. In deep swift water it is necessary to hold the lower part of the supporting pipe, or rod, by means of an adjustable stay, or guy, reeved through a pulley at some point upstream from the measuring station.

In the turbine tests the dynamic orifice of the Pitot tube was connected to the interior pipe while the static orfice was connected to the space between the outer casing, which was a one-inch gas pipe, and the inner pipe, which was a quarter-inch gas pipe. From the two nipples, about ten feet above the Pitot tube, two rubber tubes led to the manometer tubes, which were of glass attached to a board supported vertically at the side of the tail race.

One more digression will be made before the coefficient is determined. This will be for the purpose of discussing Mr. White's determination of the coefficients of Pitot tubes *M* and *N* when rated in still water. The writer's determination will be for the case of a Pitot tube, corresponding in form to Mr. White's tube *N*, in perturbed water.

In Table *V* of Mr. White's paper the results of simultaneous ratings of tubes *M* and *N* are given. In this case the true velocity was the velocity of the rating boat carefully determined. In general the velocities were 4 or 5 feet per second. Table No. 3, following, gives the simultaneous velocities as measured in the ratings. The reader is cautioned, however, that, in compiling these results, the writer has not had opportunity to assure himself that there are no typographical

errors in the figures of Mr. White's paper as they appear in the copy from which Table No. 3 is compiled.

TABLE NO. 3.

COMPILED FROM TABLE *V* OF MR. WHITE'S PAPER.

Observation.	True Velocity.	Velocity by Tube *M*.	Velocity by Tube *N*.
1	4.59	4.54	4.69
2	5.23	5.22	5.13
3	4.12	4.13	4.33
4	4.06	4.14	4.32
5	5.14	5.19	5.15
6	4.74	4.79	4.83
7	4.82	4.83	4.82
8	4.07	3.84	4.01
9	3.23	3.13	3.13
10	5.52	5.45	5.41
Sum	45.52	45.26	45.82

Mean coefficient, tube $M = 45.52 \div 45.26 = 1.006$;
Mean coefficient, tube $N = 45.52 \div 45.82 = 0.993$.

Where there are likely to be serious discrepancies between observed magnitudes of the same kind, the value of consolidating the results of many observations cannot be overestimated and opportunity is here taken to emphasize that important fact.

This method of comparing the *aggregates* of velocity for the purpose of eliminating accidental variations and errors is that adopted by the writer in his paper on current meters.

TABLE NO. 4.

PITOT TUBE RATINGS COMPILED FROM TABLE *VI* OF MR. WHITE'S PAPER.[11]

Observation.	True Velocity.	Velocity by Tube *M*.	Velocity by Price Meter.
1	2.388	2.446	2.435
2	2.410	2.385	2.430
3	1.928	1.873	1.945
4	1.837	1.844	1.895
5	1.550	1.542	1.578
6	1.550	1.556	1.550
7	1.075	1.085	1.125
8	1.088	1.075	1.115
13	1.042	1.063	1.070
14	1.122	1.118	1.148
15	1.504	1.498	1.505
16	1.475	1.514	1.475
17	1.828	1.830	1.865
18	1.904	1.863	1.900
19	2.120	2.134	2.148
20	2.198	2.168	2.200
21	2.317	2.372	2.383
22	2.378	2.365	2.340
23	2.502	2.593	2.592
24	2.660	2.608	2.645
25	2.710	2.770	2.665
26	2.830	2.783	2.840
Sum	42.416	42.485	42.849

Mean coefficient, tube $M = 42.416 \div 42.485 = 0.9984$
Mean coefficient, Price Meter $= 42.416 \div 42.849 = 0.9899$

[11] Velocities less than one foot per second have been omitted as unreliable.

If the foregoing figures are to be relied upon it must be admitted that the coefficients of the two Pitot tubes rated in these experiments are, on the average, extremely close to unity, with a probability that the coefficient of tube M is slightly greater than that of tube N. The ratings were computed on the supposition that the true formula for the head on the Pitot is $v^2 \div 2g$ and that the coefficients of both tubes were unity. It is possible that the static orifice of tube M was slightly affected in the tests of Table No. 4, where the velocities were considerably lower than those of Table No. 3, but the writer has no further evidence of the fact than that the mean coefficient of this tube is slightly less than unity as computed from the data of Table No. 4.

Another very interesting fact appears in the results of Table No. 4. The Price meter does not give as accurate results in these tests as the Pitot tube. Further, the velocities determined from the still water ratings of this meter, as given in the fourth column of the table, are, on the average, in excess of the true velocity. This excess appears to be about one percent. In the writer's paper on current meters, which has already been referred to, the following conclusion concerning cup meters is given:

"When a cup meter is run in perturbed water it will register a larger number of revolutions per second than a perfect still-water rating would indicate."

The greater the disturbance in the water the greater the excess over the perfect still-water rating. It follows that if the water is relatively more agitated in the velocity measurement than in the still-water rating upon which the velocity is based, the velocity will be in excess of the true velocity but if the water is relatively more disturbed in the rating than in the velocity measurement the velocity measured will be deficient. In general, the conditions will be more favorable in the rating than in the velocity measurement because, in general, a greater effort will be made to secure ideal conditions in the rating. It is not surprising, therefore, to find that a cup meter failed to give as good results as the Pitot tube in the experiments quoted.

COEFFICIENT OF THE PITOT TUBE IN THE TURBINE TESTS

In order to check the meters in the turbine tests about 100 simultaneous velocities by the Haskell meter and the Pitot tube were taken in the tail races. These observations were not taken in all seven of the depths but were taken only in depths 2, 3, 5, 6, and 7. This was rendered necessary by the fact that the Pitot tube did not fit the staging in the tail race for depths

Fig. 11. Boat Rigged for Stream Gauging.

1 and 4. It was not thought of sufficient importance to warrant making any changes in the apparatus, since it was merely intended to secure direct comparisons between the meter and the Pitot tube in the races.

The following table gives the results of the comparisons for 99 observations and a comparison of the aggregate velocities in a manner similar to that employed in Tables No. 3 and No. 4. About 40 Pitot tube readings were taken for each velocity by the meter.

TABLE NO. 5.

SUMMARY OF PITOT TUBE AND HASKELL METER COMPARISONS FOR 99 VELOCITIES TAKEN IN DEPTHS 2, 3, 5, 6, 7 IN THE TAIL RACES.

(About 4000 individual readings of the head indicated by the Pitot tube were made for the purpose of determining the figures of this table).

Depth.	No. of Expt's.	Pitot.	Meter.	Ratio. $P \div M$.
2	22	76.55	72.59	1.055
3	22	82.03	81.98	1.001
5	22	86.11	86.37	0.998
6	14	59.11	60.17	0.982
7	19	80.73	82.06	0.984
Totals	99	384.53	383.17	1.004

The ratio of the aggregate Pitot velocity to the aggregate Haskell velocity by the table is 1.004, showing that, on the average, the velocity by the Pitot tube is greater than that by the meter. But it must be observed that the velocities for the different depths are not equally weighted, while there is considerable difference in the ratio for different depths. It will, therefore, be proper to derive a ratio of aggregates which will not be subject to this objection in such large measure.

Table No. 6 gives the writer's revision of the figures:

TABLE NO. 6.

CORRECTED PITOT TUBE AND HASKELL METER COMPARISONS.

(Compiled from Tables 2 and 5).

Depth.	True Velocity Table No. 2.	Velocity by Haskell Table No. 2.	Ratio of Vel. by P to Vel. by H Table No. 5.	Computed Velocity by Pitot.	Coefficient of Pitot Tube.
2	3.98	3.90	1.055	4.11	0.968
3	4.48	4.44	1.001	4.44	1.010
5	4.92	4.89	0.998	4.88	1.009
6	5.57	5.55	0.982	5.45	1.021
7	6.17	6.15	0.984	6.05	1.020
	25.12	24.93		24.93	1.008

Mean coefficient of Pitot tube in tail races = 25.12 ÷ 24.93 = 1.008.

The true average velocities in the five depths are taken from Table No. 2 and arranged in the second column while the corresponding velocities for the Haskell meter are arranged in the third column. The ratio of the Pitot velocity to the Haskell velocity corresponding, taken from Table No. 5 is arranged in the fourth column, while the computed Pitot velocity appears in the fifth column. The computed Pitot velocity is found by taking the product of the corresponding figures in columns 3 and 4.

The coefficient of the Pitot tube in the last column is the ratio of the true velocity to the Pitot tube velocity. Hence, by thus changing the weights of the velocities, there is a corre-

sponding alteration of relative magnitude between the Pitot and Haskell velocities. Whereas, in Table No. 5 the aggregate for the Pitot tube indicates a greater velocity than that for the Haskell meter, in Table No. 6 the aggregates by the two instruments are exactly equal. But, another conclusion drawn by the writer in the paper on current meters was therein stated as follows:

"When a screw meter is run in perturbed water it will register a smaller number of revolutions per second than a perfect still-water rating would indicate."

If this rule is correct, it must follow that the coefficient of the Pitot tube is greater than unity, which in fact the ratio of the aggregates computed at the end of the table shows to be the case.

It is, of course, true that the coefficient of the Pitot tube, as well as that of the meter varies from depth to depth in the tail races, but it has not been thought by the writer that these ratios were sufficiently well determined to admit of detailed analysis. It is also clear that, as computed, the records of the Pitot tube and Haskell meter *cross* each other as the instruments rise from the bottom of the race to the top. This is due to the fact that the Pitot tube is probably very nearly correct in all depths and velocities, giving only slightly deficient velocities, while the Haskell meter is, as has been shown, almost exactly correct at the bottom but somewhat more deficient in its records near the top than the Pitot tube. It was therefore decided to employ the aggregates of velocity for all the depths rather than to enter upon ground requiring a degree of accuracy probably not realized in the experiments.

It may be of interest in closing to describe a boat rig which may be conveniently employed on large rapid streams of considerable depth where it is intended to determine the discharge by means of a Pitot tube or current meter. Figure 11 shows a common form of ferry boat rigged for use with a Pitot tube, or current meter. A projecting platform is built out over the bow so that the Pitot tube, or meter, which is lowered at the extremity of the platform, will not be affected by the proximity of the boat. In order to be assured as to this point different experimenters have frequently recommended that

the instrument be at least six feet in advance of the boat. Any one of the hooks on the supporting pipe of the Pitot tube can be engaged with the round part of three *U*-shaped pieces of rod, which were flattened at the ends and bolted to the projecting platform. One of these *U's* can be seen at each corner of the platform in front and one at the middle under the flag which is inserted in a hole bored in the railing. There are two other holes bored in the railing, one at each corner immediately over the corresponding *U*. This flag is always placed over the *U* upon which the meter, or Pitot tube is to be held. The flag thus indicates to all who are observing the operation of the gauging the exact location of the velocity which is being, or about to be, measured.

The next important part of the equipment of the boat is a comparatively low post a few feet back of the platform which is the king post from which the boat swings when an observation is being made. It is very important that the boat be swung from this post as, otherwise, when the boat is held in the stream from shore by two cables, one to each side, the boat will not be fully manageable. For example, if a cable were attached to each corner of the bow of the boat and these cables led off to the corresponding shores it would be found that as the boat approached either shore it would swing at an angle with the current and could not be placed in convenient positions for manipulating the gauging instrument. The king post as thus described enables the boat to be placed at any angle with the current. This will be found to be a very important desideratum where the soundings are to be taken with a rod in a deep swift current. With this rig soundings in 25 feet of water flowing 8 or 10 feet per second can be easily and accurately obtained.

The method of locating the boat in the stream over the meter points which are usually pre-determined is as follows: The cross-section is marked out on both sides of the river by ranges which can be seen from all parts of the river along the section. A transitman is located on shore at an advantageous point where he can *cut in* the signal flag previously mentioned. The observers on the boat keep the craft on the range as it is warped across the section by winding up on one of the winches

which carry the shore cables and paying out on the other. A little practice and proper proportions should develop great speed in passing from station to station and in placing the boat so that the signal flag is immediately over the proper meter point.

The location of the points on shore at which the cables are made fast is of the utmost importance. If they are too far up-stream the boat cannot be made to cover the entire cross-section and if they are too far downstream the cables may snap. They should be made fast at such an elevation that they will not

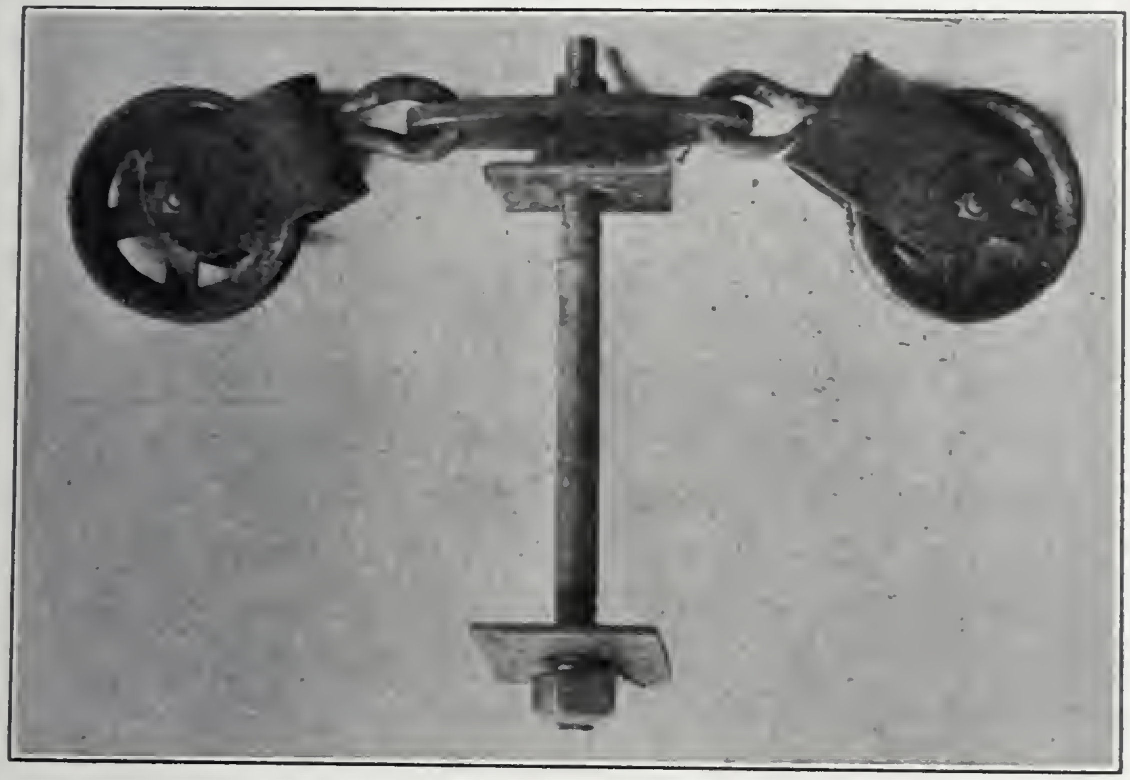


Fig. 12. Twin Sheaves for Shore Cables.

drag in the current. On a stream 700 feet wide, 25 feet deep and having a current of about 8 feet per second at all points, the cables were led up-stream about 65 feet from the gauging section and made fast 40 feet above the water in order to hold the 32-foot ferry scow shown in the illustration. The cables run through *Siamese twin* sheaves pivoted through the articulation to the top of the king post which has already been mentioned. These sheaves are an important little item and are illustrated in Fig. 12. It is clear that the cables should be as small as strength will safely permit. In the case cited $\frac{3}{16}$ inch, 7-strand, steel cables were employed.

In order to manipulate the sounding rods or to hold the

meter, or Pitot tube, it is necessary, in swift water, to guy the rods from the bowsprit which is shown in Figure 11 projecting out over the water ahead of the scow. The guy for this purpose is reeved through the small pulley at the end of the bowsprit and can be handled and adjusted from the boat.

After taking several days to equip the boat, to arrange handy fastenings for the cables to high trees on either shore and to make other necessary preparations, the cables were stretched across the channel in a terrific down-stream wind, velocities were taken at 120 meter points distributed among 27 stations together with the soundings at the stations, and the cables then removed, all in a single day. The wind, of course, greatly hampered all maneuvers.

APPENDIX

THE CHEMICAL METHOD OF TESTING TURBINES

Owing to the large amounts of money which have recently become dependent upon the results of hydraulic turbine tests and to the fact that most of the tests which have been executed in the past are to be looked upon with more or less suspicion, it is important to examine the methods and instruments which have been employed in such tests. The volumes of water to be measured being relatively large, it is rare that the discharge can be found by direct measurement. Current meters and Pitot tubes are more or less unreliable unless extraordinary efforts and expense are undertaken. Weirs are scarcely less uncertain, even where the conditions are favorable to their use. The moving screen seems to offer many advantages, but, like the weir, its installation for temporary testing does not appeal to one looking for simple means. The chemical method, when fully appreciated, will appeal to any one as being very simple of application, at least in principle, and apparently very inexpensive. Moreover, it is the only method which is theoretically exact with the single exception of the direct method of measuring the volume or weight of the water. It further appears that this method has been applied repeatedly with great success in a number of dif-

ferent countries and for various purposes but is scarcely known in America.

The chemical method of measuring discharge is mentioned by Professor Moody. The writer is now preparing to test a number of large turbines by the method of titrations; has made a careful study of the literature upon the subject; and offers the following exposition of the principles involved with some practical suggestions applicable to large units operating upon low heads.

The chemical method seems first to have been described by Schloesing in France (1863), afterwards applied by Stromeyer in England (1896) to the measurement of boiler feed, condensing water and stream discharge. More recently it has been applied by Louis to the gauging of turbulent mountain torrents in the Pyrenees and by others in France and Germany to the discharge of turbines.

In view of these facts it will be appropriate to offer a brief description of the methods along with some references to published papers upon the subject, most of which were supplied to the writer by Abraham Streiff, Civil and Hydraulic Engineer, Jackson, Mich.*

Perhaps the most difficult discharge to measure is that of a turbulent mountain stream. Let us suppose, therefore, that we select the up-stream, or dosing, station above a cataract, or rapid, where the thorough mixture of the chemical will be effected. If the concentration of the chemical solution employed be C grams per liter of water and the solution be introduced at the dosing station at the rate of q liters per second, while the

*Th. Schloesing in Comptes Rendus de l'Academie des Sciences de Paris (1863).

Jaugeages par Titrations, par M. A. Boucher, ingénieur, et Application de la Titration des chlorures au Jaugeage de Débits, par M. le Dr. R. Mellet, privat-docent a l'Université de Lausanne. Bulletin Technique de la Suisse Romande, Nr. 11, 10 Juin, 1910. Lausanne.

La Mesure du Débit dans les essais de Turbines Hydrauliques par E. F. Cote et H. Bellet. A. Gratier & J. Rey, Editeurs, 23 Grande Rue, Grenoble, 1909.

Mesure des Débit des Cours d'Eau par les Methods Chimiques, Le Génie Civil, LVIII, No. 24, p. 497 (1910-11).

Le Génie Civil, XLIV, No. 26, p. 411.

Proceedings of the Institution of Civil Engineers, Vol. CLX, article by Stromeyer on Gauging Streams by Chemical Means (1904-5).

Transactions of the Institution of Naval Architects, Vol. 37, p. 226 (1896). Stromeyer.

Bulletin No. 1, Service Hydrographique National Suisse, par Dr. Leon Collet, directeur, Berne, 1913.

Gauging Streams by Chemical Means, Engineering News, Dec. 14, 1905.

Measuring Turbine Discharges with Salt Solutions, by Abraham Streiff, Engineering Record, **Jan. 31, 1914.**

chemical analyses of samples of water taken above the dosing station, and at the sampling station below the rapid, give concentrations of c_1 and c_2 respectively, then it is clear that the discharge of the mountain torrent must be

$$\dagger\ Q = \frac{C - c_2}{c_2 - c_1} q. \qquad (18)$$

If we wish to be very particular, as in the case of measuring the discharge of a turbine, and if the dosing station be above while the sampling station be below the point at which the discharge is to be ascertained we easily deduce

$$Q + q = \frac{C - c_1}{c_2 - c_1} q. \qquad (19)$$

If the water be initially free from the chemical which is introduced at the dosing station, the analysis would show that $c_1 = 0$. Hence the discharge would be given by

$$Q = \left(\frac{C}{c_2} - 1\right) q, \quad c_1 = 0. \qquad (20)$$

But, if the discharge at the sampling station is required and there be none of the chemical initially present, the formula would become

$$Q + q = \frac{C}{c_2} q, \quad c_1 = 0. \qquad (21)$$

In order to have a satisfactory analysis, there must be sufficient of the reagent present to give the required degree of precision. Thus, if the measurement is to give the discharge with a permissible error of about one percent, and the balance employed in the gravimetric analysis will turn for one-tenth part of a milligram, then the sample taken at the sampling station should contain at least 10 mgr. of the chemical introduced at the dosing station. That is, at least 10 mgr. more than the stream contains initially. It is, therefore, necessary to determine the quantity of solution to be introduced at the dosing station. The rate of dosing in liters per second is given by

$$q = \frac{c_2 - c_1}{C - c_2} Q. \qquad (22)$$

†This equation results simply from the consideration that the total quantity of chemical passing the dosing station must equal that passing the sampling station below.

Thus $Qc_1 + qC = (Q + q)\, c_2$

This involves a minute error by imposing the equality of q on the left to q on the right. In most cases q on the right may be taken $= 0$.

If we know in advance the approximate discharge and from a preliminary analysis the value of c_1, then the necessary concentration, c_2, determines the value of q in Equation 22. The concentration, C, is arbitrary up to the point of saturation.

Suppose, for example, that it is desired to determine the rate of dosing when the approximate discharge is 50 cubic meters per second, that is, 50 000 liters per second, and the dose is a saturated solution of sodium chloride, containing 312 grams of salt per liter. Then, if the water contains no salt initially and it is desired to have 1 mgr. of salt in each liter of sample we shall have $c_2 = 0.001$, $c_1 = 0$, $C = 312$ and $Q = 50\,000$ or

$$q = \frac{0.001 - 0}{311.999} 50\,000 = 0.16 \text{ liters per sec. by equation 22.}$$

If, however, the sample is treated with a precipitating reagent, the equivalent weight of the precipitate must be introduced in the equation. Let p be the equivalent weight of the precipitate per gram of the dosing chemical. Then Formula 22 becomes

$$q = \frac{r - c_1}{C - r} Q = \frac{P - c_1 p}{Cp - P} Q. \qquad \text{(23)}$$

Here r is the ratio of the weight, P, of the precipitate per liter of sample to the equivalent weight, p, of precipitate per gram of dosing chemical. If $c_1 = 0$, the equation may be put in the form

$$q = \frac{1}{\frac{C}{r} - 1} Q = \frac{1}{\frac{Cp}{P} - 1} Q, \quad c_1 = 0. \qquad \text{(24)}$$

These equations, consequently, take the same form as equation 22 when the equivalent weights of the participating reagent are employed in place of the weights, c_1, c_2, and C, of the dosing chemical, as might have been anticipated.

Suppose it be required to determine the rate of dosing and the total amount of salt for a test of an hour's duration in the case of the stream above, where the discharge is known to be approximately 50 cubic meters per second and the sample is to be treated with silver nitrate, a common reagent for this purpose. Let it further be required that the samples should con-

tain 1-mgr. of precipitate per liter. This precipitate will be silver chloride. In order to determine the equivalent weight, p, of silver chloride per gram of sodium chloride it is necessary only to observe that a molecule of salt, $NaCl$, precipitates a molecule of silver chloride, $AgCl$. The atomic weights of the elements involved are:

$$
\begin{aligned}
Na &= 23.0 \quad \text{Sodium} \\
Cl &= 35.5 \quad \text{Chlorine} \\
Ag &= 107.9 \quad \text{Silver}
\end{aligned}
$$

Therefore

$$p = \frac{\text{molecular wt. of } AgCl}{\text{molecular wt. of } NaCl} = \frac{107.9 + 35.5}{23.0 + 35.5} = 2.45$$

Therefore

$$r = P \div p = 0.001 \div 2.45 = 0.000408, \text{ and}$$

$$q = \{1 \div (765\,000 - 1)\}Q = 50\,000 \div 764\,999 = 0.0655$$

liters per sec.

There are 3600 seconds in one hour. Hence the total number of liters of dosing solution required for the test is $3600 \times 0.0655 = 236$, and since each liter contains 312 grams of salt there will be required a total of $236 \times 312 = 73\,700$ grams, or 73.7 kilos of salt. These results are obtained with the aid of equation 24, which, in many cases, gives practically the same rate as equation 23. If it is desired to have the samples contain 10-mgr. instead of 1-mgr. it is clear that about ten times as much chemical will be required, etc.

There are many other chemicals and reagents which may be employed for chemical gauging some of which are specifically mentioned in the paper by Stromeyer on "Gauging Streams by Chemical Means", previously referred to.

A milligram of precipitate per liter of water is very little. When the solution is very dilute resort may be had to evaporation when it is impracticable to increase the rate of dosing above a certain amount. The rate of dosing, of course, should be as high as possible. So far as the chemical test is concerned, however, evaporation has the same effect as increasing the rate of dosing.

The volumetric method appears to the writer to be more expeditious and better adapted to the convenience of the engi-

neer. The general principle of this method is that if a known volume of sample requires a certain volume of standard solution containing a given weight of reagent per unit volume in order completely to reduce the dosing chemical in the sample, then the concentration of the dosing chemical in the sample can be calculated. The end of the reaction is sometimes ascertained by noticing a characteristic change in color or by having an *indicator* present. For example, if common salt be precipitated with silver nitrate, the indicator may be chromate of potassium. While the reaction proceeds a white precipitate of silver chloride continues to form; but the least excess of silver nitrate reacts upon the potassium chromate to form a very intense brick-red precipitate of silver chromate. The end of the reaction may thus be determined with nicety.

In addition to the notation already adopted let

c_s = the concentration of the reagent in the standard solution in grams per cubic centimeter.

v = volume in cubic centimeters of the standard solution required to reduce the sample volume.

V = sample volume, or the volume in cm^3 of the sample treated with the standard solution.

e = equivalent of the dosing chemical per gram of the chemical in the standard solution; i. e., the ratio of the molecular weight of the dosing chemical to the molecular weight of the chemical in the standard solution.

In the formulas the subscripts $_1$, $_2$, $_3$, will be employed as relating to corresponding quantities with like subscripts.

With this notation, therefore, it is easy to show that

$$c_2 = \frac{v_2 c_s e}{V_2} \quad \ldots\ldots (25)$$

$$c_1 - \frac{v_1 c_s e}{V_1} \quad \ldots\ldots (26)$$

Consequently that

$$Q = \frac{C - \dfrac{v_2 c_s e}{V_2}}{\dfrac{v_2 c_s e}{V_2} - \dfrac{v_1 c_s e}{V_1}} q \quad \ldots\ldots (27)$$

If all samples are rigidly limited to the unit volume, or

if the reactions are reduced by calculation to unit volume, then $V_1 = V_2 = 1$, and the following formulas result:

$$Q = \frac{\dfrac{C}{c_s e} - v_2}{v_2 - v_1} q, \qquad V_1 = V_2 = 1 \ldots\ldots\ldots (28)$$

$$Q + q = \frac{\dfrac{C}{c_s e} - v_1}{v_2 - v_1} q, \qquad V_1 = V_2 = 1 \ldots\ldots\ldots (29)$$

$$Q = (C \div v_2 c_s e - 1)\, q \qquad c_1 = 0 \ldots\ldots\ldots (30)$$

$$Q + q = (C \div v_2 c_s e)\, q \qquad c_1 = 0 \ldots\ldots\ldots (31)$$

If the standard solution is silver nitrate, $AgNO_3$, and the dosing chemical sodium chloride, $NaCl$, we shall have for the atomic weights, in addition to those already employed, oxygen $= O = 16$ and nitrogen $= N = 14.01$. The ratio of the molecular weights is then

$$e = \frac{NaCl}{AgNO_3} = \frac{23.0 + 35.46}{107.88 + 14.01 + 48.00} = \frac{58.46}{169.89} = 0.344$$

Within the reciprocal of this ratio it is easy to calculate a degree of concentration for the standard solution which will greatly facilitate the determination of the concentrations in the various samples by titration. In the case of the chemicals mentioned above the reciprocal is:

$$\left.\begin{array}{l}\text{Equivalent of the standard chemical}\\ \quad\text{per gram of dosing chemical}\end{array}\right\} = \frac{1}{e} = 2.91$$

Thus, in the case of silver nitrate and salt, if each liter of standard contain 2.91 grams (or milligrams) of nitrate, then for each liter of standard consumed in titration up to the end reaction, there will be one gram (or one milligram) of salt present in the sample. It is merely necessary then to note the number of cm^3 of standard consumed in the titration and treat this number as expressing, in thousandths of the unit chosen, the weight of the dosing chemical contained in the sample. In other words the concentration of the standard solution may be so adjusted that the volume of the standard consumed is numerically equal to the weight of the chemical to be determined.

M. Ch. Louis, an engineer in Hautes-Pyrenees, has employed the volumetric method with success upon the mountain tor-

rents of that region. It is stated that, in such cases, it is easy to treat solutions containing about one centigram of marine salt per liter without being an experienced chemist.

In applying the method there are various sources of error which must be eliminated before a high degree of precision is attainable. There may be present in the stream, initially, other chemicals which are reduced by the standard, or the dosing chemical may be affected by them. There may be mineral springs feeding the stream between the upper and lower stations. There may be additions, or abstractions, of water or of chemical, at various points between the stations. The natural salinity of the stream may be variable. The indicator employed in the samples may act upon the standard chemical, which is the case to a slight extent where chromate of potassium and silver nitrate are employed.

It must not be supposed, therefore, that such ratios as p and e can be correctly deduced for practical cases from the atomic weights of the simple elements. In any practical case the chemicals employed for dosing the water, as well as the reagents, are not likely to be chemically pure. Hence these values must be determined from the results of carefully executed tests where precision is necessary, or what is the same thing, methods must be adopted which will eliminate the errors.

A procedure very simple in principle has been suggested by M. Louis. To each sample of exactly one liter, add 1-cm^3 of the bichromate of potassium solution containing 5-grams per liter, shake and add silver nitrate solution until the persistent red color appears. Let it be supposed that v_2 — cm^3 is the volume added, and that q was the rate of dosing at the upper station. Then take q — cm^3 of the dosing solution and dilute with a sufficient volume of the natural river water to cause 1-liter of the resulting solution to react under the same conditions as did the sample taken from below. That is to say, so as to require v_2 — cm^3 of the silver nitrate solution to give the same red color as before. If it be found necessary to add Q liters of the natural river water to get the foregoing reaction, the required discharge will be Q liters per second.

It is not necessary in the dilution test above to employ the same quantities, Q and q, as when dosing the stream. It is

only needful to have them relatively the same. Thus, if Q^1 and q^1 are, respectively, the quantity of natural river water and the quantity of dosing solution which have to be mixed to produce the same reaction observed when treating the sample taken from the sampling station we should have $Q : q = Q^1 : q^1$, in which proportion all quantities are known except Q.

If we have accurate subsidiary chemical analyses to determine the values e and e^1 in the cases of the tests of the samples taken from the sampling station and also of the diluted samples made up from the natural river water and the dosing solution, we may write the following equations:

$$Qc_1 + qC = (Q + q)\ c_s ve \quad \ldots\ldots (32)$$

$$Q^1 c_1 + q^1 C = (Q^1 + q^1)\ c_s v^1 e^1 \quad \ldots\ldots (33)$$

Here v and v^1 are the respective volumes of the standard solution consumed by the samples from the sampling station and the dilution described above. If c_1 be eliminated from these equations, either of the two following equations may be obtained:

$$Q = \frac{qQ^1\ (C - c_s ve)}{q^1\ (C - c_s v^1 e^1) + Q^1 c_s\ (ve - v^1 e^1)} \quad \ldots (34)$$

$$Q + q = \frac{q\ (Q^1 + q^1)\ (C - c_s v^1 e^1)}{q^1\ (C - c_s v^1 e^1) + Q^1 c_s\ (ve - v^1 e^1)} \quad . (35)$$

If, instead of the accurate analyses for e and e^1, the procedure recommended by M. Louis be adopted, we should have $v = v^1$ and consequently $e = e^1$. Hence $ve = v^1 e^1$. and there results

$$Q = Q^1\ (q \div q^1), \qquad ve = v^1 e^1 \quad \ldots\ldots (36)$$

$$Q + q = (Q^1 + q^1)\ (q \div q^1),\ ve = v^1 e^1 \quad \ldots\ldots (37)$$

as was anticipated above.

In case $c_1 = 0$, equations 32 and 33 furnish at once

$$Q + q = (Q^1 + q^1)\ (qv^1 e^1 \div q^1 ve), \qquad c_1 = 0 \ldots (38)$$

M. Louis has made the following test comparisons:

Discharges by weir, Bazin formula	592 : 381 : : 266 : 109
Discharge by chemical method	592 : 394 : : 270 : 111

In the case of the weir the aggregate was 1348 while in the case of the chemical method it was 1367. The relative discrepancy is, therefore, about 1½ percent.

The method devised by Dr. Mellet of the University of Lausanne, previously cited, appeals to the writer as the one most likely to eliminate errors and give exact results. It is particularly applicable to turbine testing. A brief synopsis of the method follows:

It has already been explained that chemical reactions may take place subsidiary to those between the principal chemicals present in the solutions treated. In particular a certain excess of nitrate of silver is necessary to act upon the indicator producing the change in color which attends the end of the reaction. After an extended research concerning the chemistry of very dilute solutions, Dr. Mellet announces that this excess is proportional to:

First: The total volume of solution.

Second: The total quantity of precipitate which remains suspended in the solution for a longer or shorter period of time.

Third: The total quantity of indicator (potassium chromate) present.

It follows that, if we reduce the samples approximately to the same *volume and approximately to the same* concentration and at the same time keep the quantity of indicator proportional to the volume of the standard employed the excess of the standard required in any case will be proportional to the total quantity of standard consumed.

If x be the relative amount of the excess required with reference to the total quantity of standard necessary for the titration, then the method described above for treating several solutions will cause x to be a constant ratio in all the titrations, supposing, of course, that the same standard solution be employed in all.

Recurring to formula 18, it will be seen that if the three concentrations C, c_1 and c_2 can be determined, the discharge Q may be found when the rate, q, of injecting the dosing solution is kept rigidly constant at some previously determined value. It is further clear, that if all three solutions be titrated subject to Dr. Mellet's rules, the excess of silver nitrate required to act upon the indicator in each solution will be proportional to the volume of the standard solution introduced. If v_0, v_1, v_2, re-

spectively, be the volumes of the standard required per liter of the three solutions having the concentrations C, c_1, c_2, then we shall have

$$C = v_0\ (1 - x)\ c_s e$$
$$c_1 = v_1\ (1 - x)\ c_s e$$
$$c_2 = v_2\ (1 - x)\ c_s e$$

If these values of the concentrations be substituted in formulas 18 and 19 we shall have, after cancelling the common factor, $(1 - x)\ c_s e$

$$Q = \frac{v_0 - v_2}{v_2 - v_1}\ q \qquad (39)$$

or

$$Q + q = \frac{v_0 - v_1}{v_2 - v_1}\ q \qquad (40)$$

These formulas show that, by adopting Dr. Mellet's method, we have eliminated all quantities except the volumes of the standard solution consumed in the three titrations and the rate of injecting the dosing solution. In short, it is not even necessary, by this method, to know the concentration of any of the solutions including that of the standard. Neither is it necessary to determine, or to subtract from the volumes of the standard, the excess of silver nitrate required to act upon the indicator, this having been eliminated by cancellation.

In order to illustrate the process, Dr. Mellet has given the results of an actual test upon a turbine of the Day power plant at Vallorbe, as follows:

The dosing solution was introduced into the turbine at the rate of $q = 0.1211$ liters per second. This solution and the normal feed water of the turbine were sampled before the test. At the end of the 6th and 9th minutes of the test samples were taken from the tail race.

Ten cubic centimeters of the dosing solution were diluted to one liter and 10-cm^3 of this liter taken for titration. It required 35.5 cm^3 of silver solution, or $v_0 = 355\,000$.

One liter of the normal feed water was reduced by evaporation to 10-cm^3 and this required 3.8-cm^3 of the silver solution or $v_1 = 3.8$.

Dr. Mellet determines the size of the tail race samples so

that, when they are reduced by evaporation to 10-cm^3, they will each contain *approximately* the same quantity of dosing chemical as did the 10-cm^3 from the diluted liter of dosing solution which was, conveniently, 1/10000 of the quantity of chemical in one liter of dosing solution. If the discharge of the turbine is roughly estimated, and each tail race sample be of such a size that it contains as many cm^3 as there are liters per second of discharge, and if the rate of injecting dosing chemical be about 1-decaliter per second, the tail race samples will be properly proportioned in accord with the principles explained.

A rough estimate of the discharge of the turbine indicated that it was from 100 to 300 liters per second. Hence, following Dr. Mellet, the tail race samples should contain from 100 to 300-cm^3 each.

Sample No. 1, taken at the end of the sixth minute contained 200-cm^3 and, when evaporated to 10-cm^3, required 33.5-cm^3 of the silver solution, which corresponds, therefore, to 167.5-cm^3 per liter, or, $v_2 = 167.5$.

Sample No. 2, taken at the end of the ninth minute, contained 150-cm^3 and, when evaporated to 10-cm^3, required 25.15-cm^3 of silver solution, or, $v_2 = 167.67$.

These values might now be substituted in Formula 39 or Formula 40 according to the circumstances of the test, but Dr. Mellet makes the calculation very simply and with sufficient exactness as follows:

Sample No. 1. $Q = 0.1211 \dfrac{355000}{167.5 - 3.8} - 0.1211 = 262.4965$ liters per sec.

Sample No. 2. $Q = 0.1211 \dfrac{355000}{167.67 - 3.8} - 0.1211 = 262.2241$ liters per sec.

These values differ by about 0.1 percent which is about the limit of error mentioned by Dr. Mellet for such a case.

In order to carry out such a test successfully, one should be thoroughly acquainted with the details of the process as set forth in Dr. Mellet's valuable paper. However, the following directions for conducting the titrations and evaporations may be of interest to the engineer.

The dosing solution is diluted in such a manner, that 10-cm^3 will contain several centigrams of the salt.

One liter of the normal feed water is evaporated in a procelain casserole 10-*cm* in diameter, into which the liquid is poured by degrees as fast as it evaporates. This evaporation to 10-cm^3 takes place in a bain-marie.

The sample from the tail race or lower sampling station is evaporated in the same manner to approximately the same volume, the volume of the sample being so taken that we shall have several centigrams of the salt to titrate.

The titration takes place in a porcelain casserole, (for the solutions evaporated, in the same casserole which has served for the evaporation). To 10-cm^3 of the liquid to be titrated first add 2-drops of the chromate solution, then introduce slowly the silver solution from the burette. If the proper tint does not appear after the addition of 10-cm^3 of this solution ,add a drop of the chromate, and continue the titration, and so on, until the color does change. This titration takes place beside a second casserole of the same size, containing the liquid for comparison. This latter is prepared at the moment needed, with 10-cm^3 of chloride of sodium solution 2-drops of chromate and 9-cm^3 of silver solution.

One of the most important questions for the engineer to determine is the method for effecting a perfect mixture of the dosing solution with the water of the stream to be gauged. In the case of mountain torrents the question is comparatively clear. In the case of broad sluggish rivers it is quite the reverse. It is also easy to see that, in the case of turbine testing, there may, or may not be, serious difficulties. In the case of a single runner discharging into a long tail race, where there is ample opportunity for the mixture to be effected, it would seem no serious trouble should be anticipated. In the case of a single one of several units taking water from a single flume, each being driven by several runners connected to the same shaft it may prove very difficult to secure the same degree of concentration for all of the runners of the unit being tested.

The course recommended by the writer in the latter case is to make use of current meters in a preliminary test to determine

the distribution of velocities in the forebay of the unit to be tested. By sub-dividing the cross section into a sufficient number of partial areas of equal discharge and by dividing the uniformly flowing stream of dosing chemical equally among these partial areas, the rapidity of mixing may be greatly accelerated. A further aid is to employ a centrifugal pump for performing a part of the mixing. The pump takes its water from the forebay above the point where its discharge is equally divided among the partial areas of equal discharge. The dosing chemical is fed to the pump through a pipe connected to the suction. It is clear that the pump must run at a perfectly uniform rate and that every effort must be made to have its discharge equally divided among the partial areas. The dosing chemical must be fed at a uniform rate as in all other cases. All the details of this method will depend upon circumstances and success will follow only upon the exercise of good judgment and substantial engineering skill.

If the discharge, Q, equations 19 and 40, is practically constant, it must follow that $Q + q$ is practically constant also, since q has been assumed constant. In this case q need not be maintained *rigidly constant* so long as it is small *relatively to* Q. Thus, if Q is 50 000 liters per sec. and q is 5 liters per second, of a concentration of 250 grams per liter, then q may be altered to 10-liters per second without altering $(Q + q)$ by more than $5 \div 50\,000$; that is by more than 1/100 percent, which is negligible in tests of 1/10 percent precision.

Therefore, in the case considered, q may vary between the limits 5 and 10 liters per second, that is by 100 percent, without affecting the results, provided an *average* sample from the tail race be taken and the simultaneous total volume of salt solution injected during the test be observed.

Thus in the case of *constant, or nearly constant, turbine discharge,* the constant head device may be omitted. But a *continuous sample* should be taken from the tail race at a *practically constant rate.* The total volume of salt solution consumed may then be read from a calibrated scale on the side of the salt-solution tank while a liter of the continuous sample, or samples, from the tail race furnishes the average sample or samples, as the case may be.

It would seem that the best method of introducing the strong salt solution would be by means of a system of perforated pipes in the head-race connected directly to the salt-solution tank, while the continuous tail-race sample could be pumped up from a similar system of much smaller, say ¼-inch, perforated pipes. A large centrifugal pump might be employed, as already described, while a smaller one agitates the strong salt solution or pumps the dissolving water through the dissolving box before beginning the test.

The latter remarks apply particularly to large discharges. For example: If $Q = 50\,000$ liters per second it would require, at 0.03 grams per liter, 1.5-*Kg.* of salt per second. For 1-hour's test it would take $3600 \times 1.5 = 5400$ Kg. or nearly 6-tons of salt. If 50 tests averaging, say, 4-tons of salt are to be run, it would require 200 tons of salt, which would cost upwards of $400, freight and handling not included. If the tests can be shortened in duration a corresponding saving can be effected.

The writer sees no reason why, with precise chemical and engineering methods, under the direction of a skilled engineer and chemist, it would not be possible to determine the discharge to within one-tenth, or even one-hundredth, of a percent of its true value. In taking samples it is suggested that each be large enough to leave a liberal residue, after the first chemical treatment, for any subsequent tests which may prove to be necessary. This precaution may save the necessity of repeating a large part of the work.

[The discussions of these papers will be published in the June, 1914, issue of the Proceedings.—Editor.]

[A partial Bibliography on Pitot tubes is given on pages 381-383.]

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It is desired to acknowledge the assistance of the Technology Department of the Carnegie Library of Pittsburgh in the preparation of the above bibliography.

MEASUREMENT OF THE VELOCITY OF FLOWING WATER

By Lewis F. Moody*

PITOT TUBE FORMULAS—FACTS AND FALLACIES

By Benjamin Feland Groat†

[These papers were published in the May, 1914, issue of the Proceedings of the Society, p. p. 279-383. Additional discussion, if received will be published in a later issue.]

DISCUSSION

Mr. Gardner S. Williams‡: In reading the two papers that have been presented tonight there are one or two cautions that I would throw out to start with. The first one is this, that in my experience with Pitot tubes I have had occasion to rate the same instruments in still water by dragging attached to a car, and also to test them in running water where the water passing the instrument is determined by measurement. I have never been able to get the two ratings to agree. In other words, it is my opinion that a still water rating of a Pitot tube does not give a rating that we would get with the same instrument if it were rated by running past it a measured quantity of water. I suppose the reason is that the tube passing through still water drags with it a small volume that does not show the difference in pressure between the tube itself and the surrounding water; whereas in running water the vibrations or pulsations of the water itself tend to keep the instrument from forming such an envelope. That, of course, is only speculation and it may be entirely wrong, but the fact remains.

The second thing I would suggest is that I am not ready yet to accept the high degree of accuracy which the papers pre-

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sented might lead us to believe was to be obtained by either Pitot tube or current meter measurements. When we come to think that in gaugings by either of those devices there is occupied at the very best perhaps ten percent of the area of the stream to measure its velocity, we are hardly warranted in saying that we know enough about the other 90 percent of the area to be within one percent of the actual discharge.

I had occasion not long ago to have a Haskell meter rating made under somewhat exceptional conditions, as it was desired to see what would be the effect of turbulent water. A quantity of water passing down the experimental canal at Cornell University was measured over a weir, and was then measured by a current meter in the hands of Professors Schoder and Turner of the instructing staff of the University. There were some nine gaugings made and the work was done with all the care with which those gentlemen were familiar. Professor Turner had been in the employ of the United States Lake Survey and had participated in the stream gauging work on the St. Mary's River, according to the practice of the United States Lake Survey, which represents about the highest type of current meter work that has ever been produced. And it was Mr. Turner's testimony, under oath the other day, that the methods at Cornell were in entire harmony with, and of equal accuracy as far as manipulations were concerned, to those of the United States Lake Survey, with which he was familiar.

The results of those investigations showed that in the turbulent water which existed in the canal, and it was not more turbulent than is encountered frequently at gauging stations in streams, the Haskell meter under-registered in the extreme case something over 9 percent and in all cases over 3 percent.

Now the subject which these gentlemen have taken in their papers tonight has been the formulæ of the Pitot tube. It makes very little difference practically what that formula is; if you rate your tube and apply either of the so-called equations to it, the result you get when you use that tube and apply that rating will be of equal accuracy in similar conditions which ever formula you use. But here is something to think about. The Pitot tube elements consist of two parts, an orifice which receives the impact of the stream and the orifice which

transmits the pressure at some point in the stream. The difference between the two is that from which the velocity of the stream is computed. It is assumed that the impact opening communicates the effect of the impact plus the pressure, and that the pressure opening communicates the pressure, the difference between the two being the effect of impact. If the pressure at the impact orifice, and the pressure at the place where that pressure is measured be the same, then the deductions as given here tonight are correct. But if the pressure at the point of the instrument and the pressure where the pressure orifice is located be different, then their deductions are not so accurate.

In dealing with a closed tube, under ordinary conditions, the velocity at the center is at least twice the velocity at the wall, as nearly as we are able to measure. That does not apply near the entrance of the pipe, where the velocities are disturbed much more than they are in a stream of water after it has flowed through a pipe for something over 100 diameters, when you can expect that the velocity at the center will be to the velocity at the wall in about the ratio I have stated. By that I mean the velocity as near the wall as you read it, which is really not very near.

Bernoulli's theorem states that the sum of velocity head, pressure head and head of elevation must be a constant in any stream line if friction be neglected. And conceiving all the water at a certain cross-section of a pipe to be deriving its energy from the same head, it may be reasoned that where the velocity is greatest the pressure must be least and vice-versa. It must be manifest that this does not hold rigidly in naturally flowing water on account of the influence of oblique currents, etc. Some years ago I undertook to obtain some light on this subject experimentally, and for the reason that I have never completed my experiments they have never been published. I left Cornell before they were finished and since that time have had neither time nor opportunity to go on with this work. But at Cornell University I went far enough to satisfy myself, at least, that the pressure at the center of the pipe is less than it is at the wall.

The experiment which I tried was, in brief, to take an

instrument consisting of a flat plate, having an orifice connected with a small tube, and starting at the wall, move this plate across the stream, keeping it always parallel to the axis of the pipe. I found that at the wall the pressures transmitted through the orifice coincided almost exactly with those indicated on the perforations in the periphery of the pipe in the same plane. As the orifice passed out to the center, the pressure appeared appreciably less, and as it got over to the farther side the pressure came back nearly to that indicated by the peripheral orifices.

Time is too short to go into the details of those experiments but I simply present these facts for the thought of the gentlemen here, and suggest that, if at the point of the instrument, Bernoulli's theorem holds, and the pressure is actually less than at the wall by the amounts of the difference in velocity heads, then it follows that the impact opening must indicate something considerably greater than $v^2 \div 2g$.

If you take a Pitot tube point for the impact opening and connect it with orifices in the wall in a circular pipe under normal conditions of flow, the diameter when traversed will give a mean velocity corresponding with the measured mean velocity of the water within something less than 2 percent by the formula $h = v^2 \div 2g$. The traverse will usually show slightly the higher quantity. In other words, the coefficient of the instrument will appear to be a little less than unity. And as to that 98 percent referred to by the authors, there have been several hundred traverses made by myself and others associated with me which bear out their statement. There is no question about that part of it. But even that does not prove that the impact opening transmits $v^2 \div 2g$. I have not prepared a mathematical equation or a mathematical analysis for presentation tonight, but in the American Civil Engineers Pocket Book, page 873, you will find a brief discussion of the Pitot tube, where the analysis of this problem, as I see it, is set forth.

MR. EDWARD S. COLE*: It has been a great pleasure to listen to the two very able papers of the evening particularly as they offer convincing evidence of an increasing interest in the Pitot tube, as a means for measuring the flow of water.

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In 1896, under the direction of John A. Cole, C.E. of Chicago, I began, at Terre Haute, Ind., a series of experiments with the Pitot tube in order to produce a practicable instrument based upon that principle for use in gauging the flow of water in the street mains of that city.

There was a scarcity of information available at that time, and what little I could find was not encouraging—for example, on page 259 of "Merrimans Hydraulics" (5th Edition), we read: "Pitot's tube has been but little used and is generally regarded as an imperfect instrument for velocity determinations."

Notwithstanding this, and other discouraging statements, a very reliable form of Pitot tube was evolved after a long and costly series of tests.

We soon found a decided advantage in the use of the duplicate orifice, one bent up stream and the other down stream. Not the least of the advantages gained was *reversibility* for check readings and for prevention of orifice clogging.

The static orifice projecting into the main, with its orifice plane parallel to the flow, was suggested by a crude sketch in "Carpenter's Experimental Engineering" of that period, and it was not until after much labor that this form was seen to be hopelessly unreliable. On turning this static tube into a down stream curve, our troubles were at an end so far as uniform indications were concerned.

It would be tiresome to describe the difficulties of those early days in developing a method which now appears so obvious and simple. Thus a suitable manometer for registering the difference of orifice pressures was hard to find. The presence of air in the apparatus was a stumbling block. The use of a heavier liquid, such as carbon tetrachloride, immiscible in water and giving a pre-determined "differential" action, was worked out independently and was novel so far as we know.

In the same way the method of flow computation, depending on a velocity "survey" of the pipe area had to be developed.

The conception of a fixed ratio of mean to center velocity did not come to us until much time had been lost in vain attempts to relate the center velocity to pipe diameter and discharge direct. The varying condition of the pipe wall, of

course, made our weir measurements of flow appear inconsistent, and at last we saw that every pipe must be "surveyed" or "traversed" to give its own velocity distribution. The ring method of integrating flow followed in due course.

Other developments such as the Photo-Recorder made the instrument more complete and efficient. For our form of Pitot tube and recorder, we coined the word *PITOMETER,* intending it to be distinctive, but now this word has come into general use and seems to be applied to Pitot tubes of any form.

After several years, we found that others had been working independently in the field, notably Gardner S. Williams, C.E., whom we have with us this evening. His tests made at Detroit are well known.

With this hasty sketch of early development days, you may understand the pride I take in such a discussion as this, proving that my early faith in the Pitot tube method has been vindicated, and after constant use of our Pitometer in engineering tests, covering a period of fifteen years in upwards of eighty cities, I feel qualified to speak as to its accuracy and value.

Throughout this long period, thousands of Pitometer gaugings have been made under my supervision for a variety of purposes and in pipes of all sizes from the 4 in. to 60 in. cast iron mains of city water works distribution systems to steel penstocks, of water power plants, as large as 16 feet in diameter. All of this work has been done under conditions requiring the highest attainable degree of accuracy. Often large sums of money have depended upon Pitometer gaugings, as in the case of a large factory found stealing water to the extent of half a million dollars. Large centrifugal pumps have been tested for fulfillment of contract conditions as to the capacity and efficiency, sometimes requiring new runners at great expense, as a result of the Pitometer gauging.

Hundreds of pumping engines have been tested for net discharge and here the requirements have been unusually severe. Often the "slip" of the pump has been called in question and verified by other means, such as weir or reservoir test, but after years of public use the Pitot tube method is more than ever recognized for its accuracy. Hydraulic laboratories in various

parts of the United States are now equipped to make calibration tests of Pitot tubes and they too have added to our faith.

In view of exceptional experience in this line, I feel qualified to make one criticism of Prof. Groat's paper, regarding the degree of accuracy attainable with Pitot tube or Pitometer, viz: I cannot believe that it is safe to claim results involving less than one percent error in hydraulic experiments of this kind.

By way of comment on Prof. Moody's paper, I would say that his method of obtaining static heads in large penstock tests does not seem to me as reliable as my own Pitometer method of carrying the static orifice along with the dynamic orifice across the pipe in making the velocity "traverse."

In reference to the over reading of the sharp dynamic orifice in oblique flow or turbulent conditions, I think this must apply to the readings of the single orifice or plain Pitot tube, rather than to our double form, as we once made careful gaugings of flow in seven 36 in. pipes, each receiving the discharge of a large centrifugal pump at Torresdale, near Philadelphia. Pitotmeter gaugings made just below the pump gave the distribution of velocities characteristic of spiral flow with re-entrant center and $V_m \div V_c = 1.02$. Nevertheless, a simultaneous gauging some distance down stream in the main pipe, gave the same flow value within one percent though based upon a normal velocity curve with its $V_m \div V_c = 0.87$.

In view of this result, it is hard to see how oblique flow could have had any material effect upon our instrument.

Mr. N. C. Grover*: The two papers read this evening (The Measurement of the Velocity of Flowing Water, by L. F. Moody, and Pitot Tube Formulas, Facts, and Fallacies, by B. F. Groat) treat of the same general subject with particular reference to the measurement of velocity of flowing water by means of the Pitot tube. They may therefore well be discussed together.

In both papers the accuracy of velocity measurements made by the Pitot tube is discussed, and comparisons with the Haskell and large Price current meters are shown. Mr. Groat describes also in some detail the equipment and methods employed by him in making a measurement of river discharge by means of this instrument. No attempt has been made in either paper, how-

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ever, to define the probable field of usefulness of the Pitot tube, and the listener is left to assume that it may become the universal velocity meter of the future. The remarks which I shall make pertain to the relation of the Pitot tube to the practical problems of the hydraulic engineer in the measurement of river discharge, rather than to the details or even the merits of the papers themselves.

My interest in these papers arises from my connection with a branch of the Federal Government in which for the last ten years more than seventy-five engineers (on an average) have devoted their time and energies to the measurement of river discharge. This interest is, therefore, more than the academic one which an engineer ordinarily takes in a phase of professional work with which he may never come in active contact or perhaps that he may have occasion to touch only at infrequent intervals. As the measurement of the velocity of flowing water is an essential part of the work of the water resources branch of the Geological Survey, its engineers are constantly on the lookout for possible improvements in methods or instruments, and especially for those which promise increased accuracy of results. Whenever improved methods are found to be practicable for general work they are adopted, frequently at great expense for new equipment necessary on abandoning that previously used. Having in mind, therefore, the possibility of improving the work of stream gaging of the Survey, I have applied to the two papers presented this evening the same question that I apply to all similar papers; that is, are the methods or instruments suggested applicable to the work of the Survey, and, if so, are they improvements on the methods or instruments now in use? With the same object in view I am discussing these papers in the hope that the authors or others may suggest modifications or improvements in instruments or methods which may be practicable for general use.

The end sought in measuring the velocity of water is generally the determination of discharge. This determination may be made for one of several purposes. For example, the records collected by the Geological Survey are made for general statistical purposes and may find their greatest use in connection with future *development* work, or, as is frequently the case in the

more highly developed portions of the country, with the *operation* of hydraulic works. On the other hand, the work of Mr. Groat, which was used as a basis for his paper, had for its object the determination of the efficiency in place of certain water wheels installed in a power plant. Obviously the limits of accuracy allowable and consequently the instruments and methods employed might properly be different for such widely varying problems, and the best methods for work of either class, if applied to the other, might represent as poor engineering practice as would the application to the survey of relatively cheap farm or forest land, of the precise instruments and methods necessary for the delimitation of valuable city lands. Special problems, like that which confronted Mr. Groat, require special instruments and methods. A record of the experience of one man helps another who is attempting to solve a similar problem. Frequently, too, such special investigations lead to results that are of general interest and bring about changes in methods that are of far-reaching importance. The chances for such important results are especially good in an art like that of the collection of records of river discharge, in which all recognize the possibilities of improvements.

In the methods and instruments which he adopts, therefore, the hydraulic engineer must discriminate between those problems requiring relatively great accuracy, like that investigated by Mr. Groat, in which errors of less than one percent may have caused the acceptance or rejection of expensive water wheels with the possibility of much more expense in litigation in case of rejection, and those relating to the measurement of discharge of a river, which varies widely from day to day, season to season, and year to year, and which never repeats itself. The fact that certain surveys do not warrant the highest degree of accuracy should not, however, be put forth as an excuse for poor instruments or poor work, because neither is ever excusable in important investigations. The stream-gaging work of the Geological Survey has, from its inception, been conducted with a much higher degree of accuracy than would be warranted by the probable use of the resulting data. Such action, has, in my judgment, been entirely proper because the records are published under governmental seal and are accepted as standard

for all purposes except those requiring extraordinary detail. Obviously such records should be collected with exceptional care. Engineers in private practice should recognize, however, that the annual Congressional appropriation for steam gaging by the Survey in the whole United States is little or no more than may be actually expended by private or municipal corporations in the investigation of a single project for the development of water power or of a municipal water supply. As a result of this situation the cost of every phase of the work must be carefully considered and the methods and instruments adopted must be intensely practical and must give reliable results under a wide range of conditions. A Survey engineer leaves the office on a field trip covering, let us say, a single river basin. A part of the gaging stations which he must visit are located in the lower course of the river, where large quantities of water flow at all stages, and part are located on head-water tributaries too small to be called rivers and designated either as brooks in the Northeast or as creeks in the South and West. When he leaves the office to make the trip the rivers are perhaps all at low stage and he expects to make a series of low-water measurements. Before he returns he may have measured the discharge of streams in flood, and almost certainly he will have made some measurements by wading and others from bridges or cables located many feet above the stream. He will have measured the discharge of streams varying in depth from 1 to 50 feet and in velocity from 0.50 foot to 15 feet or more per second, and in character of water from the clear trout-brook of the mountains to the silt-ladened river of the plains. He will have traveled with his full equipment by steam cars and trolley, by stage and livery, by motorcycle and automobile, by rowboat and horseback, and surely many miles on foot. Most of his measurements will have been made in isolated localities where it is impracticable to secure assistance, and yet he must return to the office with dependable results. Excuses will not be accepted for failure at any point. Obviously the instrumental equipment for such work must be simple, light, and universally adaptable. The specifications for a current meter for such work are not easily met. Many meters have been tried, a few have fulfilled the major requirements, and none has been com-

pletely satisfactory. Within the life of the water-resources branch of the Survey and its forerunners—the hydrographic branch and the hydrographic section—practically every known form of meter has been tested in our field work, and our junk room is filled with meters that have cost thousands of dollars but that have been discarded, not in general for failure in accuracy, but because of lack of adaptability to the wide variety of conditions in which we must work. The large Price meter, like that used by Mr. Groat in his investigation, is one of the types that has been tried and was several years ago discarded because of lack of reliability. With the abandonment of this type alone fifty servicable meters, which had cost upwards of $3,000, were scrapped. The small Price meter, which is now used by the Survey, has been changed again and again; old forms have been abandoned or remodelled to make way for the new, and perfection is not yet reached.

Many valuable and widely used methods have of course been developed for measuring water. The Chezy formula and its modifications are invaluable for making rough estimates of flow from observations of slope. The weir in its many forms finds perhaps a greater use than any of the other devices for measuring discharge, as practically all measurements in connection with the distribution of water for irrigation are made by this means. With the exception of the calibrated tank, which is not adapted to general use, the weir is generally recognized as the most accurate device for measuring small quantities of flowing water. Reference should also perhaps be made to water meters of various types and to orifices, all of which are valuable for particular purposes.

Returning again to instruments for measuring velocity, floats, surface, sub-surface, and tube have a wide use but they cannot be relied on to give accurate results except under special conditions. The Fteley meter is perhaps the most accurate of current meters within the limits of its practicable use. The Haskell meter is strong, generally reliable, and durable and is recognized as one of the very best for work on large rivers. The small Price meter, which is believed to be the best of the cup type, is not extremely accurate when used in turbulent water or under conditions that cause a vertical motion of the

meter, but otherwise is the most universally adaptable of the meters now made in the United States. When used under proper conditions this meter will give results which will check either the calibrated tank or the sharp crested weir within reasonable limits of accuracy. There are many modifications of these types of meters which have found favor locally but which have not become widely known.

It is comparatively easy for you or for me to explain wherein this meter or that meter falls short of the ideal, and it is important that we should know the shortcomings of each. It is much more difficult, however, for us to make the real improvements which all so much desire. The engineers of the Geological Survey are searching constantly for improvements, not only in the meter used, but in other meters which give promise of greater accuracy. It may interest you to know that several years ago an expert mechanician was employed by the Survey for months in an unsuccessful attempt to convert the screw type of current meter into form for universal use. A serious decrease in available funds caused the temporary abandonment of that work, and it has never been resumed. W. & L. E. Gurley have had their instrument men at work for a long time in the production of a screw meter which it is hoped will fulfill Survey requirements, and it is expected that a sample will be ready for trial in the near future. If, after trial under a wide variety of conditions, such new meter is found to be generally more accurate and reliable than the small Price meter, the latter type will be scrapped as have been the large Price and many other types in times past.

Why this extended statement of experience and prospects, you ask. The practicing hydraulic engineer, whatever his equipment for special studies, must be equipped also for a range of work similar to that of the Survey if he is to meet properly the great variety of problems presented in his practice. He should, therefore, know the specifications which his current meter must meet. These remarks are also designed to furnish in a brief way a perspective wherein the Pitot tube, in its present form of development at least, may be accorded its proper place. In my opinion, such place is in connection with special investigations. Its merits or demerits for such work I do not feel

qualified to discuss, but the experience of Messrs. Moody and Groat is certainly encouraging for its future usefulness. Each special investigation offers its pecular problems and in some of these the Pitot tube will probably find its place.

That other and improved types of current meters will be developed in the future I have no doubt, but if such new types are to displace the types now used for general work, they must have not only the qualification of greater accuracy under certain conditions but must stand the test of hard experience in the wide variety of work which stream gaging under all conditions affords.

Mr. Thomas P. Roberts*: The relative merits of the Pitot tube as against screw or cup meters is the problem attacked by Messrs. Moody and Groat, the first having his conclusions based on many experiments in still water tanks, towing the meters or tubes, the other dealing with numerous observations of moving water in large well proportioned head and tail races. So far as conditions were concerned for obtaining facts and adapting principles to them, little has been left to criticise.

Simple as Pitot tubes are in principle, for years back some of the brightest minds have exercised their wits in attempts to calibrate them for service in the practice of hydraulic and pneumatic engineers. It has been stated that they have given excellent results on natural gas lines, and fully ten years ago the results from one of them agreed with a volume meter, measuring gas, to within one quarter of one percent.

The present speaker has read the papers with interest, but not closely enough to warrant him in entering upon a critical discussion of their conclusions.

It is probably the case that the majority of engineers on river work have had personal experience only with current meters and have given but limited attentions to pitometers. Those of them, of course, who have had, besides river work, experience with gas and water supplies for communities and mills, have definite knowledge of the value of pitometers in measuring the discharge through pipes or other confined areas where current meters could not possibly be employed. However, these same engineers would not, in their river work, use the tubes.

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The present speaker, without having personal experience at any time with Pitot tubes, has always considered them, when properly made, more philosophical, i. e. nearer to nature in the field of hydrodynamics, because no wheel, screw, or other artificial contrivance with them intervenes between the force exerted and the indicator of the force.

It is the case, however, that some things which may be true in principle are not always easy of application in practice. For instance, how is the engineer to take advantage of Mr. Moody's formula for determining the effect of an oblique current against the orifice of a Pitot tube when the current is first encountered, say, 20 feet below the surface of the river. It really is the case that neither meters or tubes, as now constructed, make any record of oblique currents. This branch of the subject in the papers before us is referred to in items relating to "perturbations," when a mean of numerous readings is to be taken. There may be, and there usually is, shifting or perturbations in all currents, especially if there are high submerged rock ledges, or other considerable variations in depths, near the meter, especially in swift water. Nevertheless there may be a decided constant obliquity at a certain depth of which the pitometer will not feel the full force, but which a current meter will not fail to record at full value.

So very decided are these cross currents sometimes that they result in developing vertical eddies productive of upstream velocities, yielding minus quantities. The existence of such currents can only be determined by means of floats, and, of course, the engineer will move from such a "cantankerous" place if he can find a better one to go to.

On this subject the case is recalled of attempts to obtain the extremely low discharge of the Monongahela River in the drouth year 1908. Conditions were as follows: Practically no water flowing over or leaking through Dam No. 1; velocity of water in the pool above dam, with section 1000 feet wide, 12 feet deep, "estimated" to be 0.011 feet per second or about 40 feet per hour. As the least heard of velocity recorded by a current meter was four inches per second, it was quite evident that the river as a whole section could not be measured. Recourse was then had to measuring the lockage water, plus gate, and

valve leakage, which created perceptible currents in the lock chambers. The chambers were laid off by stretched cords in rectangles so that the course of floats could be traced. Very soon it was found that some rather large leaks directed invisible currents obliquely against the walls on one side, which rebounding, created long diagonal cross threads with upstream currents over most of the width of the locks (56 ft.). The worst of it was that the swiftest downstream threads were very narrow and did not show at the surface. Only after numerous trials with floats set for different depths (the deepest 8 ft.) did it appear possible to differentiate the areas of the downstream from the upstream threads on a given cross section. The final result was a discharge of about 200 cubic feet per second for the Monongahela which was not much from a watershed of 7400 square miles. After the floats had located the "trick points" velocities were checked with a Price meter which gave almost the same final figure. Of course, Pitot tubes might, at the same points, have given corresponding velocities, provided the tubes had been held parallel with the oblique currents. It is in such peculiar cases where the current meter will unfailingly hold its head to the current exactly as a catfish noses its way through a rapid.

As intimated, however, experience demonstrates that in gaging high floods in the Ohio below Pittsburgh not much reliance can be placed on any form of current meters, at least until after the flood crest has passed. Grass, leaves, and other matter suspended in the water, with the powerful currents existing at such times, tends to collect about the meters, often stopping the gearing, breaking the electric wire, or even pulling up the 100 lb. anchor and causing it to float up to the surface. At such times floats only can be used and dependence placed on mid depth, or sixth tenth depth, velocities, for the compartments of the general section.

It appears to be easily practicable, by means of vanes on long rods, to indicate the obliquity of currents at different depths. With such knowledge in advance, Pitot tube velocities could be reduced with nearer approach to accuracy. With such an attachment many engineers might desire to use them in clear streams in preparing curves for rating tables. More numerous

readings would likely be taken, on account of their convenience, than with the rather cumbersome meters, and for this reason alone better final results ought to be obtained.

If it is true, as has been affirmed by some writers, that tubes giving a perfect record for a given velocity will be perfect for all velocities, that fact ought to relieve the fears of those who think the best of them are not reliable under all circumstances. In a good, really honest, thermometer factory pains are taken to obtain tubes of even bore. They may look precisely alike to the most critical eye, but when tested many must be condemned. Is there not in principle an analogy between Pitot tubes and thermometers—and in cost also, where good ones must be paid for?

MR. WILLIAM KENT†: The papers of Mr. Groat and Prof. Moody are valuable contributions to the literature of the Pitot tube. They have apparently established the conclusion, that while the total pressure produced on a plane surface by a jet striking it perpendicularly may be represented by the formula $h = v^2 \div g$, the pressure indicated by a Pitot tube is only half this amount, or $v^2 \div 2g$. There was good reason ten or fifteen years ago for believing that the latter expression was incorrect, for many published experiments had shown that the actual velocity of a stream was considerably less than that calculated from the observed head on the Pitot tube, and consequently that the observed head was much greater than the head calculated from the formula $h = v^2 \div 2g$. The head being the effect and the velocity the cause, and it being impossible that an effect could be greater than the cause, it followed, logically, that the formula was wrong. Numerous recent experiments have shown, however, that when a Pitot tube is properly made and properly handled; when the static pressure is correctly measured (which in some forms of tube made for reading both static and dynamic pressure it is not); when the axis of the tube is parallel with the axis of the stream; and when there is no turbulence; the coefficient of the tube is unity, that is $v = \sqrt{2gh}$, and Messrs. Groat and Moody now show mathematically why this formula is also theoretically correct.

I have myself used a Pitot tube as a check upon other

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methods of measuring the discharge of a pump at high pressure, and found its readings (on a mercury column) to give measurements which agreed within one percent of those obtained by a calibrated nozzle and pressure gage and those obtained by a weir, using the Francis formula.

Mr. Moody's paper (p. 319) states that "the coefficient to be used with the tubes at ordinary velocities should be slightly less than 0.98." It is not clearly shown to which member of the equation the coefficient applies. It is $h = 0.98\ v^2 \div 2g$ or is it $v = 0.98 \sqrt{2gh}$? If the latter, then $h = 1.02\ v^2 \div 2g$, and it should be explained how the observed head can be greater than that calculated from the velocity.

PROF. CHARLES M. ALLEN*: We have made several hundred experiments with Pitot tubes of various types to determine the coefficients of the instruments both for a still water rating and also a moving water rating. The coefficient referred to is c in the formula $h = c\ v^2 \div 2g$. For all of our work we use the formula $h = v^2 \div 2g$, and let the coefficient c take care of any departure from that for all types of Pitot tubes.

The still water ratings were conducted at a circular current meter rating station located in a deep still water pond connected with the Hydraulic Engineering Laboratories of the Worcester Polytechnic Institute.

A steel trussed boom 84 ft. long suspended from the middle, mounted on ball bearings and rotated by means of a rope drive from a water wheel, was so arranged that any desired velocity could be obtained from something less than ½ ft. per sec. up to 10 ft. per sec.

This station has done some exceptionally good work in rating current meters of all types for the past six years and it was thought to be well suitable for rating of Pitot tubes.

The moving water ratings were made in a 40 inch pipe and at the throat of a 36 inch Venturi meter, the latter place being by far the better suited for consistent ratings.

From several hundred traverses made across the 16 inch throat, the average ratio of mean to center velocity was 0.986. The water flowing thru the 40 inch pipe and Venturi meter was measured over a 10 ft. standard weir with end contractions.

*Professor of Hydraulics, Worcester Polytechnic Institute, Worcester, Mass.

Ratings made under above conditions were consistent as shown by repeated tests, but the coefficients varied with the velocity in all cases. The amount of variation depended upon the type of tube and amounted to from one to ten percent where the velocity changed from one to twenty feet per second.

From all of the experiments made in still water with the same instruments, the coefficients vary with the velocity, but are also higher in value in every case than with moving water ratings to the extent of from 3 to 5 percent. In the still water ratings, the velocity change was from 1 to 10 ft. per sec.

From all of our experience in rating and using Pitot tubes of various types, we have come to the following conclusion: That Pitot tubes should be rated in moving water and at the same velocities at which they are to be used (or in other words, calibrating them under actual running conditions), a good motto for users of all hydraulic instruments.

We believe the Pitot tube in various forms to be accurate and reliable in the measurement of the flow of water when properly used.

Mr. Morris Knowles*: So large and enthusiastic an audience and the discussions by prominent hydraulicians, several of whom do not live in the Pittsburgh District, exhibit a growing and now well established interest in the one inexhaustible natural resource of flowing and falling water, which for so long a time has been dimmed in obscurity by the more money-making, ephemeral and much wasted resources of coal, oil and gas, which have so persistently monopolized the attention in this vicinity. All of us who hold water, well controlled, as a valuable asset, be it pure or otherwise, must feel gratified at the increasing interest shown; grateful to our officers for arranging such a meeting; and to our eminent friends for the contributions and deliberations, upon the important means of measuring the energy in this great resource.

These papers upon the Pitot tube and the related subjects of the measurement of head and velocity of flowing water, are especially interesting, in that they suggest a corroboration of theory with known experimental results. The article by Mr. William Monroe White, B.E., published by the Association of

*Consulting Engineer, Oliver Building, Pittsburgh.

Engineering Societies, in May 1901, to which reference has been freely made, is also valuable in this latter connection; as experimental proof is given for the correctness of the formula $v = \sqrt{2gh}$ when applied to the Pitot tube.

Fig. 40. Experimental Pitot Tube with Vernier attachments.

These latter experiments suggest to the writer some earlier history, which it may not be amiss to relate at this time. Ten years before and while stimulated by the epochal work of Mr. John R. Freeman, C.E., upon the gaging of hose-nozzle streams, the writer, in collaboration with the late Mr. Louis Francisco Verges, S.B., conducted some experiments upon the distribution of velocity in jets from standard orifices. These tests, which were then believed to be the first of their kind for this purpose, were undertaken as a fulfillment of thesis requirements, in the course of Civil and Hydraulic Engineering at the Massachusetts Institute of Technology in 1891, and have never been published. It has since appeared that Bazin's experiments "On the Con-

traction of the Liquid Vein issuing from an Orifice", published in the Memoires of the Academy of Science, vol. XXXII, and published in translation, by Mr. John C. Trautwine, Jr., in 1896, were being carried on contemporaneously.

Without attempting an elaborate description of the apparatus used which was especially designed for the work and

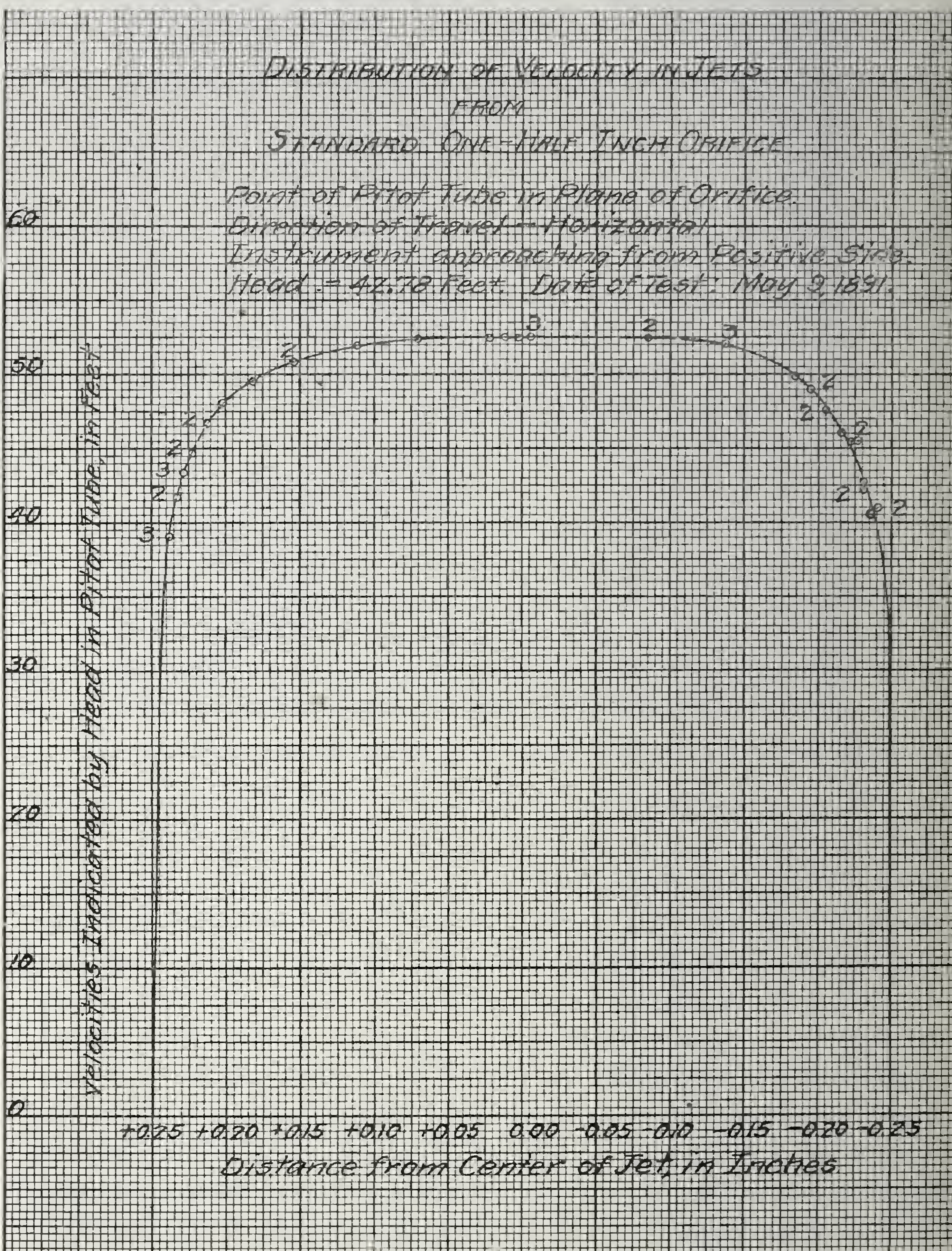

Fig. 41.

results obtained, it will be sufficient to state that a Pitot tube, of 0.011 inches internal diameter at the point, was mounted upon the flange of a ring, which was attached to a fixed annular frame on the tank and independent of the orifice plate. By virtue of the ring being threaded, so as to move in and out on the annular frame, and due to the rotating motion of the ring itself, as well as the transverse motion of the tube shank, it was possible to obtain three motions; all of which could be determined and measured on Vernier scales and by tangent screws. Thus the point of the Pitot tube could be placed in any plane of the jet, at measured distances from the plane of the orifice, and moved across this plane in any direction and at any designated angle with the horizontal and at measured intervals. A view of the apparatus is presented in Fig. 40.

The head on the orifice was about 48 feet in all tests, and the diameter of orifice 0.50 inches. The different velocities were measured by means of a *U*-tube mercury gage connecting with the Pitot tube. In calculating the velocities from the head in the mercury gage, the formula $v = c\sqrt{2gh}$. was used.

It is interesting to note that the measured velocity at the center of the orifice, as computed from the reading by use of the above formula, was found to be 1.0022 times the theoretical velocity. In order to secure the actual velocities from the readings of heads on the mercury gage, it was necessary therefore, to use a constant of 0.9978, in the formula $v = c\sqrt{2gh}$. The close approximation of this coefficient to unity affords additional evidence of the application of this formula to Pitot tubes. The fact that the effect of temperature upon the mercury was neglected and some other lack of refinements, offers a possible source of error, which would tend to make the coefficient as found somewhat less than unity. The temperature is not now known exactly, but if taken at 80 deg. Fahr., which was the warmest record for the month of tests, the coefficient would become 0.999. Subsequent thesis work at the Massachusetts Institute of Technology by John S. Hallaron in 1896 and Thomas C. Fisher, in 1913, confirm the use of a coefficient of unity.

Plots of the distribution of velocity at the plane of the orifice and at the contracted vein are presented in Figs. 41 and 42 respectively.

The writer was particularly interested in the remarks of Gardner S. Williams, C. E., relative to the applications of Bernoulli's theorem to different points in the horizontal diameter of a section. In our experiments, conducted upon jets

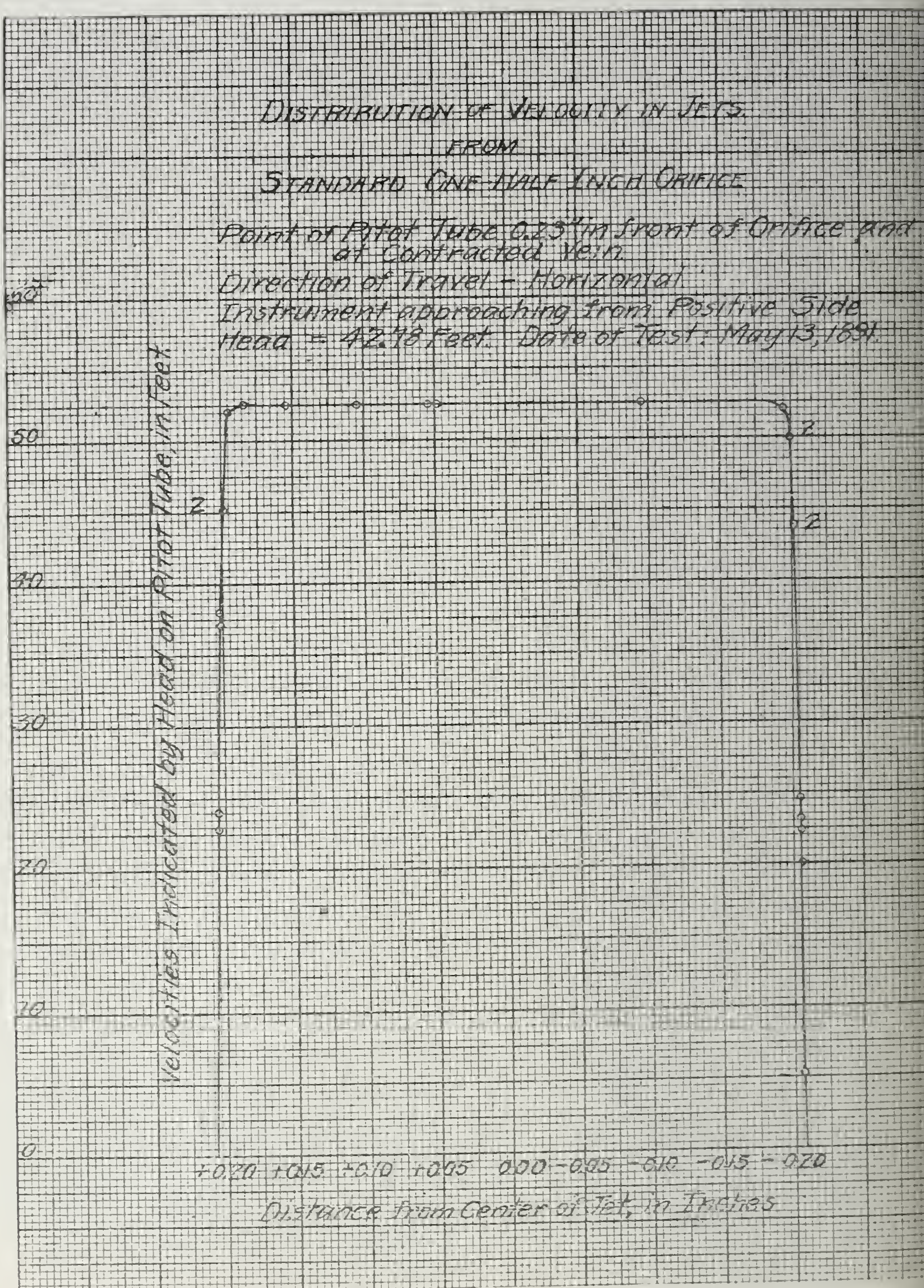

Fig. 42.

issuing from standard orifices, it was very evident, as stated by Professor Williams for pipe flows, that a marked retardation of velocity in the jet occurred about the outer edge.

If Bernoulli's theorem were applied to two points, one at the center of the jet and the other at the outer edge of the jet in the same plane, then the decrease in velocity head at the outer edge would necessitate an increase in pressure head, in order to balance the greater velocity head at the center. If such an application of Bernoulli's theorem were possible and if the outer edge of the jet were under greater pressure than the center of the jet, it is reasonable to suppose that this pressure would cause the jet to lose its form. Thus it appears the theorem is not applicable to two such points.

According to the principles of the conservation of energy, however, it follows that the total energy in a filament of water in the outer edge must equal the total energy in a filament taken at the center, granting that each has the same source of energy. It does not, however, necessarily follow that the energy must appear in the form of pressure and velocity. Undoubtedly a portion of the velocity of the outer filament must have been converted into heat due to friction. Taking this latter element into account, there seems no justification for assuming that the decrease in velocity, between that of the center filament and that of a filament in the outer edge, is compensated for by a corresponding increase in pressure.

Mr. Clemens Herschel*: In conformity to the invitation of a Member of the Engineers' Society of Western Pennsylvania, this brief discussion of the general subjects treated at the meeting of the Society held December 16, 1913, is submitted.

The distinction is not always clearly drawn between "Measuring Water", as that pioneer in the art, certainly in America, James B. Francis, of Lowell Hydraulic Experiments and other fame, was wont to call the exercise of hydrometry; and "The Measurement of the Velocity of Flowing Water."

The last named is only a step in one of the ways in which the first named may be accomplished.

Again, the sole absolute test of the correctness of any method of measuring water, is a tank measurement; and unless

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a writer on practical hydraulics clearly keeps such a check measurement in mind, and in the minds of his readers, he is liable to become self deluded, and no fit guide for his following.

FLOWING WATER

What is "flowing water"? Is it a trough or pipe contained bundle of the string like, straight line filaments of the schoolbooks, moving over or alongside of each other without friction, so that at the end of the first observed second of time, the downstream ends of some of the filaments are much in advance of the downstream ends of the others; at the end of the second second of time, these same leader heads are twice as far in advance of the last named filament heads; and so on, until in a few minutes the heads of the fast running filaments may have slipped for yards and scores of yards in advance of the heads of the slower running filaments; all of which heads were abreast of each other when the experiment began?

Nothing of the sort. The writer elsewhere has compared the particles of flowing water, instead of with such a loose bundle of strings or filaments as just described, to the "contents of a feather bed turbulently floating down the street in a gale of wind."

Now this is the sort of floating material which we are to gauge, and to say what cubic volume of it is passing a given cross-sectional plane in a second of time.

That the picture is not overdrawn will be recognized when it is considered that just as a cloud of feathers will stay together as a cloud, though each feather may be blown about in every geometric direction while partaking of the cloud's linear motion, so a small amount of coloring matter injected into a body of flowing water, has been used to determine the velocity of the whole stream, by observing the interval of time taken for the little body of cloudy water to pass a station a half mile or more down stream from the point of coloring matter injection.

Evidently we have not here to do with the filaments of the school books. And instruments pretending to measure the velocity of such filaments do nothing more than average certain cloud motion tendencies. And, again, methods of computing volumes passing a given plane in a second of time, based on the determination of such average tendencies at selected points

in the originally supposed cross-section plane, do not necessarily reveal the truth. Especially not, if these methods have not been tested as a whole, from *A to Zed,* by a tank measurement.

WEIR MEASUREMENTS

In the 50s of the 19th Century, Mr. James B. Francis, then the 30 odd year old agent of the proprietors of Locks and Canals on Merrimac River, the corporation controlling the water power at Lowell, Mass., had occasion to establish the weir method of measuring water for purposes of regulating the draft of water from the canals of his company by the seven Lowell manufacturing corporations. This he did by letting water flow over such a weir a carefully measured interval of time, and catching the water thus passed over in an old canal lock, prepared to receive it for its then duty as a tank, or measuring basin. Depths upon the weir, the interval of time elapsed spoken of, the contents of the tank, lengths of weir, means of observing the true depths upon the weir, were all designed and measured with extreme accuracy, as were also all the characteristics of the whole weir construction. All as permanently recorded in the book above referred to.

From many series of such experiments was deduced the well known Francis formula for measuring the discharge of water over a weir; but let it be noted and remembered, that this formula was stated and published as applicable only to a weir and its outfit proportioned, constructed, and built just like the weirs used at Lowell in 1850 (or thereabouts), and, in the case of depths on the weir, observed and measured just like those at Lowell were then observed and measured.

With these limitations, a careful engineer may undertake to make observations and measurements, the results of which carefully computed will, after a due interval of time taken for the computations, give rates of flow as they existed at certain recorded seconds of time.

Similarly did Messrs. Fteley and Stearns, hydraulic engineers employed in the construction of the Sudbury Aqueduct by the City of Boston, Mass., in 1877-1879, make weir gaugings, checked by volumetric gaugings; and published the results of their experiments.

They selected a method differing from that used by Mr.

Francis for observing the depth of water upon the weir, so that any one wishing to use their formula, would be obliged, if wishing to reach accurate results, to use the Fteley and Stearns method of making observations; and generally would be obliged scrupulously to imitate their procedure.

Besides all this their formula asks the engineer to add linear feet to cubic feet per second; a worship of and subservience to the occult powers of a mathematical formula, not readily undertaken by every engineer that computes quantities.

Other such weir experiments have been made in comparatively recent years in France (Bazin and others), and in Germany.

But enough may have been said to indicate that accurate gaugings do not necessarily result because a weir was used, not even if it shall have been called a "standard weir." Everything depends on the man who built and used the weir, and there are no doubt more inaccurate weir gaugings extant, than accurate ones.

Nor is the cost of a weir gauging a trifle. Weirs will not transmit water pressure, hence can only be used in open channels; sometimes only after a gross waste of water pressure. The cost of putting in a tight weir, and supplying it with the necessary hook gauges, setting the hook gauges, and making the weir observations is considerable. And after all this has been done, there remain the computations to find the practical results: which after all are only a series of rates of flow taken at stated recorded times. High priced, skilled labor has been necessary to procure all of this, and the results have been reached after long waiting, and have not been available during the time of the actual gaugings, when they were most needed.

CURRENT METER GAUGINGS

These may be made in selected points of the cross-section of a stream; or, by slowly moving the current meter in vertical, or in horizontal lines, or so as to cover the whole area in a uniform manner, the mean velocity in the verticals, or in the horizontals, or over the whole cross-section, may similarly be determined.

Again does high priced computation follow high priced observation, and again is the personal skill and equation of the

observer involved in the results, which after all have only come to hand, long after they should have been known, to say nothing of the time and cost necessary for rating, safeguarding and rerating of the current meters; nor of the fact that an hour to make one gauging is fairly quick work; this last a great grievance and disadvantage when all the other hydraulic phenomena, (such as the setting, speed and power of the turbine, say, to be tested) must be kept constant and uniform during the same length of time.

For gauging large rivers, this is an accepted method. As portrayed above, it is much less desirable in the gauging of small streams, and barely applicable to the gauging of pipe discharges.

PITOT TUBE

Everything that has been said respecting the disadvantages of gauging streams by means of current meters, applies to the use of Pitot tubes for that purpose, with the additional disadvantage that Pitot tubes will only indicate velocities for an instant of time, and only in single points of the stream cross-section.

In a pipe for example, to work in the customary manner the point of the Pitot tube, when making a gauging, must be set precisely in the circle which is the locus of the threads of velocity having the mean velocity existing in the whole cross-section. Inside of this circle by a hair's breadth and the results found are too large; outside of it, and they are too small. And always are they only instantaneous indications. Under such circumstances sustained accuracy is of course unattainable. Ordinary Pitot tube or pitometer gaugings are therefore approximations only.

High priced labor in procuring and rating the instruments; difficulty and cost of using them; the long time necessary to make a single gauging, when large streams of water are gauged and the multiple point method of observation is employed; the computations that needs must follow; the skill and personal equation of the operator involved; the time that must elapse before the paucity of results finally obtained has been found; all these militate against the use of Pitot tubes in gauging streams of water for practical purposes.

VENTURI METERS

If we had the flow of a ⅝-inch, or a 1, 2, 3 or 4-inch pipe to measure, nobody, presumably, would think of measuring that flow over a weir, or by a current meter, or with a Pitot tube. He would use instead a water meter; or might use a stop-watch, and a pail or tub.

Now it has come to pass, in the progress of things mundane, that a water meter has been devised, (invented 25 or more years ago,) some 6000 in use today the world over, applicable in pipes from ¼-inch diameter to tunnels 18 ft. in diameter, repeatedly tested, and costing less to procure or build and set in place, together with the taking of the readings (which last "the man in the street" can do,) than the cost of any of the methods hitherto described, reckoning such cost from the beginning of operations to the procural of the net results. Then why not use such a meter when it becomes a question of metering the water flowing in pipes or channels generally?

It would be difficult fully to answer this question, though human inertia and the blighting, life-long effects of misinformation acquired during the days of schooling, and thereafter from many engineering compiliations, have much to do with the omission to use such meters in the many cases where they yet should be or should have been used. Especially when it is considered that the fundamental Venturi meter patents have long ago expired, and any one may build and use a Venturi meter tube.

The first large sized Venturi meter ever built was built inside of an old 9-foot penstock in Holyoke, Mass., in 1886; of wood, and using the penstock merely as a sort of continuous hoop to hold together the wood staves. All material, (except the cast bronze throat piece) was entered through a man hole cut into the penstock, and removed in the same way.

This process was repeated 3-years later, in the case of two such meters built into two 4-foot water pipes on the works of the East Jersey Water Co., supplying Newark, N. J.; and those two meters after 24 years of service, night and day, are still "on the job." They also bid fair to serve at least as long as the 4-foot conduit does.

Many such meters have been built of concrete; in the East

Indies are two such, some 10 ft. in diameter; and in line of the new conduit supplying New York City from the Catskills are three such meters each nearly 18 ft. in main diameter.

Hundreds and thousands have been made of cast iron, the throat lined with brass, to meter cold and hot water, brine and other chemicals, illuminating gas, steam and other gases.

Built to standard proportions, they wholly eliminate the personal equation, or technical skill of the user. The same register will indicate the momentary rate of flow, the total quantity that has passed since the last reading of the meter, and a clock wound once a week keeps a chart record, night and day, during the week. The Massachusetts Metropolitan Water Board, has 66 such night and day watchmen keeping continuous records of inflow and outflow on its many pipe lines.

These last named are permanently installed meters. But for temporary, passing purposes, such meters are eminently useful and advisable. In testing turbines set in place, temporary wooden or concrete meters can, it is believed, always be set horizontally, inclined, or vertically, either in the penstock, or else in the tail race. An example of a difficult application of this sort in a masonry penstock, in which the Venturi meter tube extends upstream and downstream, from and around a bend in the penstock, is described in Engineering News, February 15, 1912.

As the most expensive part of such a meter is the register, (when a register instead of a simple indicating manometer is used) to apply the Venturi meter to water waste prevention work, it would only be necessary to use one register, portably mounted, for the whole city, or a city district, to register the flow through meter tubes set permanently in line of the street mains; and thus made available thereafter and whenever an examination for measuring waste is desired.

In point of accuracy such meters leave nothing to be desired. They have been repeatedly tested by tank measurement. Indeed, the first one sold and used outside of works being built by the inventor of the meter, (after 10 years of skepticism or else of decrying of it by engineers and others), was sold subject to test by tank measurement, to a lawyer-president of a water supply company, and thereupon kept by him. Many such tank

measurements preceded and have followed this little pioneer meter. In Engineering News of August 14, 1913, 3d page of the cover, tank tests made monthly at Lancaster, Pa., by the Engineer and Superintendent of the water works, are described. Their variance from the Venturi meter record is stated to average 1-20 of one percent.

Perhaps the most gratifying, time and expense saving, useful feature in the use of such meters is the fact that they indicate at once, in the field, all that one wants or needs to know about the gauging then in progress. To fully appreciate this service, it may be necessary for the hydraulic engineer to experience it. Thus, in making any of the ordinary hydraulic experiments which engineers undertake, it is of the greatest value to know on the ground and during progress of the experiments, what law of nature is being revealed by them. And the more readily to recognize this law, it is necessary to be able to vary the elements under examination by regular and equal increments or decrements.

Thus in testing any apparatus discharging water, it is a great help to let the discharge vary by equal increments of cubic feet per second, beginning with the minimum discharge; something which is readily accomplished by *setting* the desired discharge, by means of the meter, to equal the desired quantities; to begin with and thereafter.

If one will stop and think of the help such a procedure is to the engineer conducting say a wheel test, and of the entire absence of the personal equation in such a procedure, he will look upon the "screen method" of gauging turbine feed or discharge, mentioned in the papers now before the Society as lately introduced in the conduct of wheel tests in Sweden and Germany, (with its many assistants required to conduct the tests, and its other disadvantages), as a distinct retrogression in the conduct of turbine tests.

Finally, as to the comparative expense involved; it will never do to compare the bare cost of meters, with the bare cost of weirs, current meters, or Pitot tubes. The comparison must be made between the total expense due to the several methods used, reckoning from the beginning of operations, to the pro-

cural of the net result sought; and reckoning moreover for materials and all labor involved, skilled and unskilled.

If this is done, it will be found, so far as the writer's experience and judgment goes, that the cases are rare indeed, barring the gauging of streams of over 1000 cu. ft. per sec., in which the use of meters, whether for temporary or for permanent gaugings, will not be notably more satisfactory in many respects; and costing less, than any other method that can be employed.

PRELIMINARY REPORT OF CURRENT METER INVESTIGATIONS

MESSRS. E. H. BROWN* AND F. NAGLER†: The experimental work herein described was performed with a view to determining possible causes of the over-registering of the cup type of current meter. It is preliminary to more extensive tests which were made in order to determine the relative extent to which various types of current meters and different forms of revolving elements for each type, will give true resultant components of velocity when the meter is subjected to angular flow.

On recent tests of various hydro-electric plants it has been shown that the cup type of meter indicates a mean velocity considerably in excess of that called for by the quantity as measured by a weir, and also considerably in excess of velocities as determined by the screw type of current meter. The same relation is taken up very fully in the December, 1912, Proceedings of the American Society of Civil Engineers, by Mr. B. F. Groat. In the discussion of Mr. Groat's paper appearing in the February, 1913, issue of the Proceedings Mr. W. G. Price makes a statement which has been generally conceded by engineers. The statement appears on page 306 and reads:

"If a cup meter with no vane is fixed on a vertical rod, *the current perturbations moving up and down in the vertical plane will decrease the revolutions of the wheel* and thus offset the increase due to the horizontal perturbations. This action is due to the fact that the top and bottom faces of the meter wheel present a propeller-shaped surface to the water, and when vertical currents strike the wheel they tend to turn it in the opposite direction from that produced by the water flowing against the cups."

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This first work was performed for the purpose of determining the extent of the "decrease" mentioned in the italicized portion of this statement and in order to ascertain the effect of the meter frame on the readings of the meter when subjected to horizontal disturbance or angularity.

METHOD OF TESTS

For the preliminary work there was available a 42 in. discharge main about 500 ft. long of uniform grade. Water at about a temperature of 90 deg. flowed in this pipe to a depth of

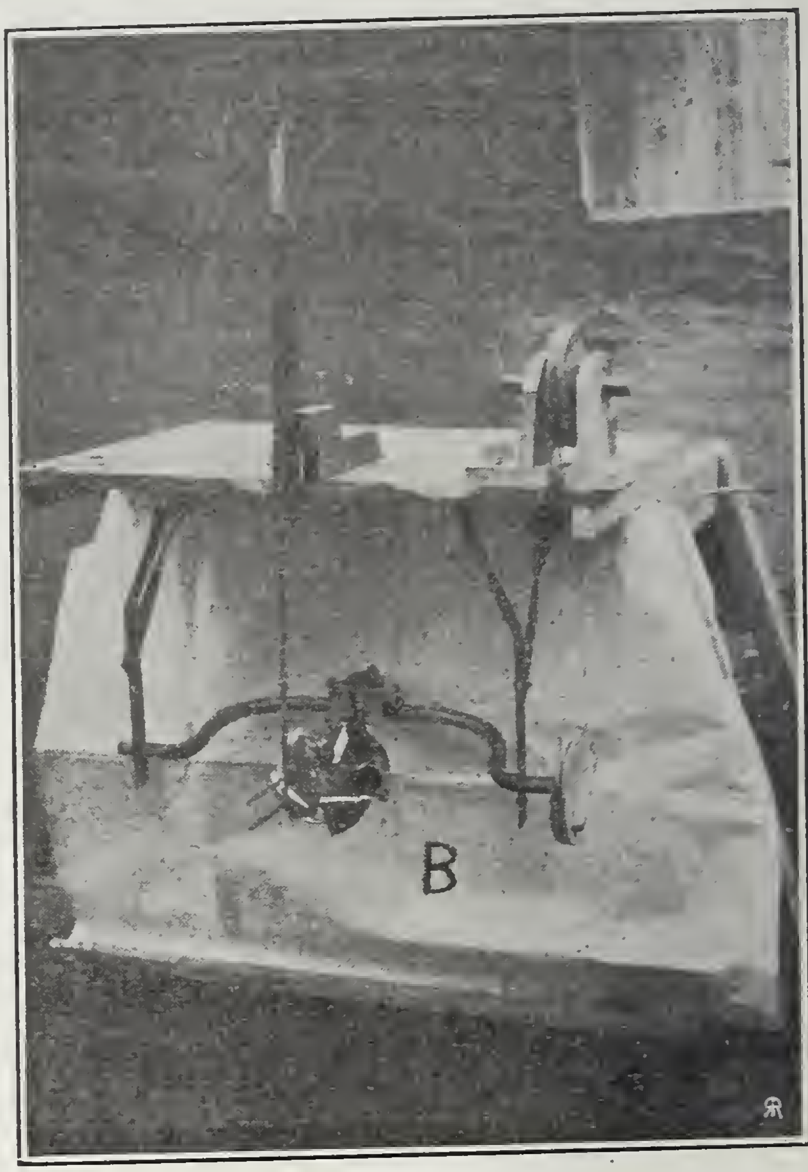


Fig. 43. Arrangement of Apparatus for Testing Current Meters.

12 to 14 in. and at a velocity of about 4-feet per second, the velocity being very constant. A large size Price type current meter manufactured by Gurley was first placed in this current and held at various angles with the horizontal, it being revolved about a horizontal axis as far as 90 deg. above and below a horizontal plane. A rigid support was provided and an indicator so arranged that the angles could be determined within

about 2-degrees, the arrangement being such that the meter could be shifted from one position to another readily. See Fig. 43. The tail of the meter was removed and it was supported rigidly in the stream by a crank of such throw that the center of the meter head remained in a fixed position for all angles.

The center line of the revolving element was placed about 5 in. below the surface of the water and 8 in. above the bottom of the conduit. A reading was taken with the meter normal to the stream every third or fourth setting so that a continuous record as to the constancy of flow might be available. The average velocity of the water at the meter position was about 4-feet per second, according to the maker's rating of the meter.

This velocity was checked by a Pitot tube which was substantially the tube *N* as used by W. M. White in his work. It was inserted, not to check the absolute velocity as measured by the meter, but rather to show whether the velocity of the water was altered due to different outlines of the meter being presented to the flow at the different angles.

RESULTS OF TESTS

In placing the meter at a slight angle either above or below horizontal, it was immediately noted that the revolutions increased very materially. At the 90 deg. positions above and below horizontal, in which positions the axis of the rotating element of the meter was in line with the direction of flow, it was expected that the meter would either reverse or show little velocity. As a matter of fact, it showed approximately one-half the number of revolutions that it registered in its normal presentation to the flow, and in the same direction.

The curve sheet, Fig. 44 shows all of the points obtained under tests. It also indicates the shifting of the whole curve occasioned by the difficulty experienced in fixing the normal position. It shows very clearly that under constant velocity of water this particular meter will over-register as high as 25 percent when placed at an angle to the normal direction of flow vertically. It is to be noted that this maximum point occurs at an angle approximately that of the side of the bucket.

In connection with the above as well as later work an error is introduced in that tipping the meter at an angle introduces a greater amount of bearing friction. The effect of

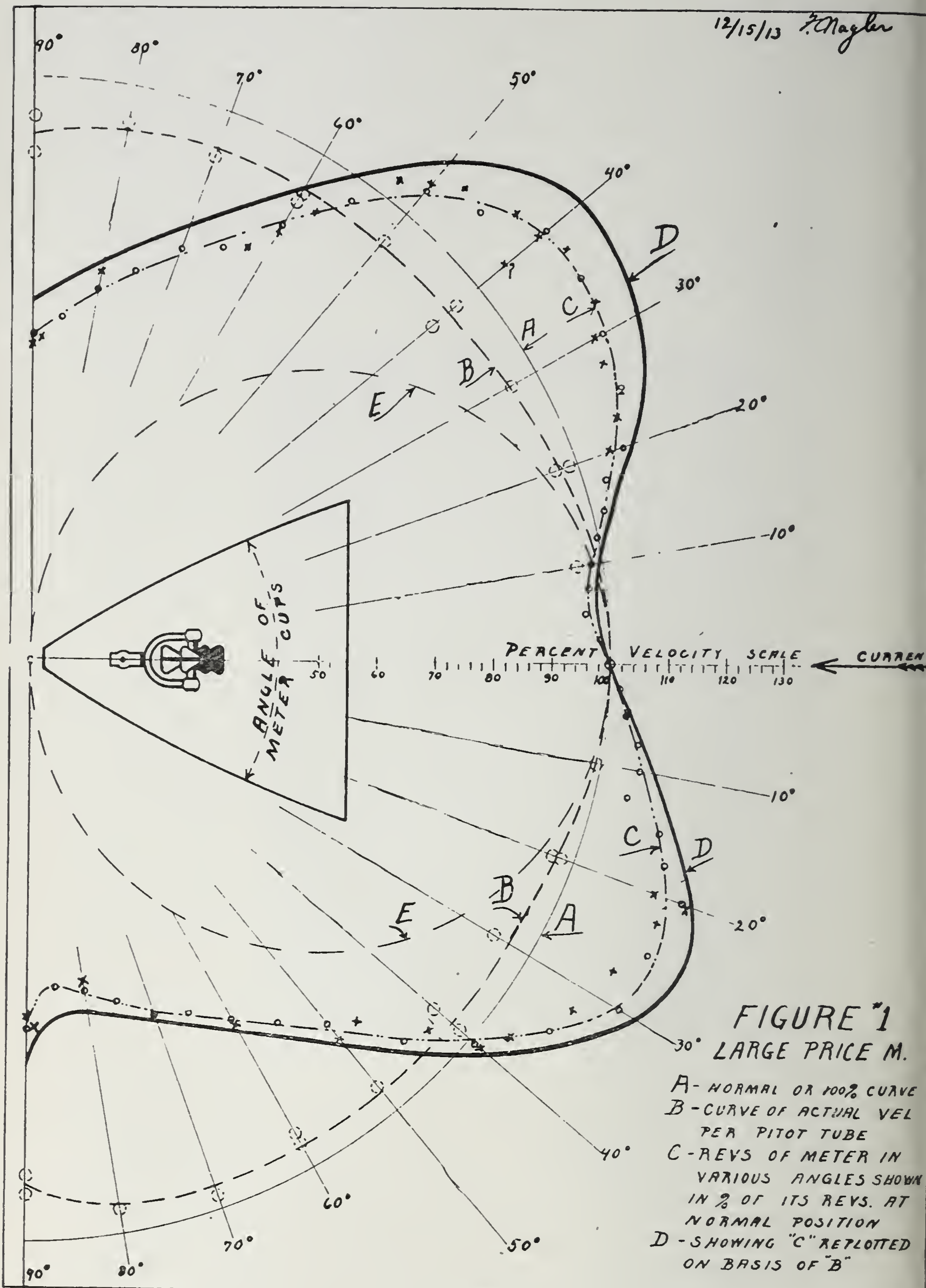

12/15/13 F. Nagler
FIGURE #1
LARGE PRICE M.
A - NORMAL OR 100% CURVE
B - CURVE OF ACTUAL VEL PER PITOT TUBE
C - REVS OF METER IN VARIOUS ANGLES SHOWN IN % OF ITS REVS. AT NORMAL POSITION
D - SHOWING "C" REPLOTTED ON BASIS OF "B"
PERCENT VELOCITY SCALE
CURRENT
ANGLE OF METER CUPS
50 60 70 80 90 100 110 120 130
90° 80° 70° 60° 50° 40° 30° 20° 10°
A B C D E

Fig. 44.

this error will not be experienced in a meter used in a horizontal position, but it is probable that the effect is slight up to the 45 degree limit used hereafter to cover all ordinary conditions. In any event the effect is merely to reduce the number of revolutions, this reduction increasing with the angle.

On the curve in Fig. 44, the circle *A* is drawn in showing the theoretical performance of the cup type of meter when placed at various horizontal angles, under which conditions neglecting the effect of the frame, it may be assumed that a constant velocity will be registered regardless of the angularity of the meter. This circle also shows the performance of any type of meter so supported that it is free to swing in any direction. The circle *E,* drawn in on one-half the diameter of *A* indicates, by the length of the various vectors intercepted, the true components of velocity and represents the ideal meter performance. The dotted curve *C* is plotted on the actual test readings of the meter under test and indicates along the 25 degree and 35 degree lines the approximate maximum error. These lines lie at an average angle of 30 degree with the horizontal, which corresponds to the 60 degree angle (approximate) of the bucket itself. This double curve *C* is plotted in on the basis of percentage of curve *A*. The error would be greatly emphasized if it were plotted in on the basis of circle *B,* which shows the true resolved components desired.

The Pitot tube readings are shown along curve *B* which is also plotted in percentage of *A*. The curve *D* is replotted in percentage of *A* by basing *C* on *B* rather than on *A*.

This preliminary work indicates that the over-registering of this particular cup type of meter is due more to the effect of angularity of flow in a vertical plane than to that in a horizontal plane. This is contrary to general ideas of performance of the cup type of meter as indicated by above quotation. In the place of retarding the revolutions of the meter under test, angularity of flow in the vertical direction speeds it up a very considerable amount over the known error due to horizontal angularity of flow. The conclusion follows that the large Price meter should only be used swinging free in all directions, in which case the excess velocity (curve *A*) registered in disturbed water will be slight for small disturbances but will increase

rapidly with large angularities. This becomes evident upon comparing curves A and E.

After making the above determinations no further work was done on the large Price meter but attention was devoted to the smaller and more modern Price single point cup type of meter as made by Gurley. This instrument was constructed with the cups conical in form, the axial sections being circular as contrasted to the triangular form of the larger instrument, see Fig. 45.

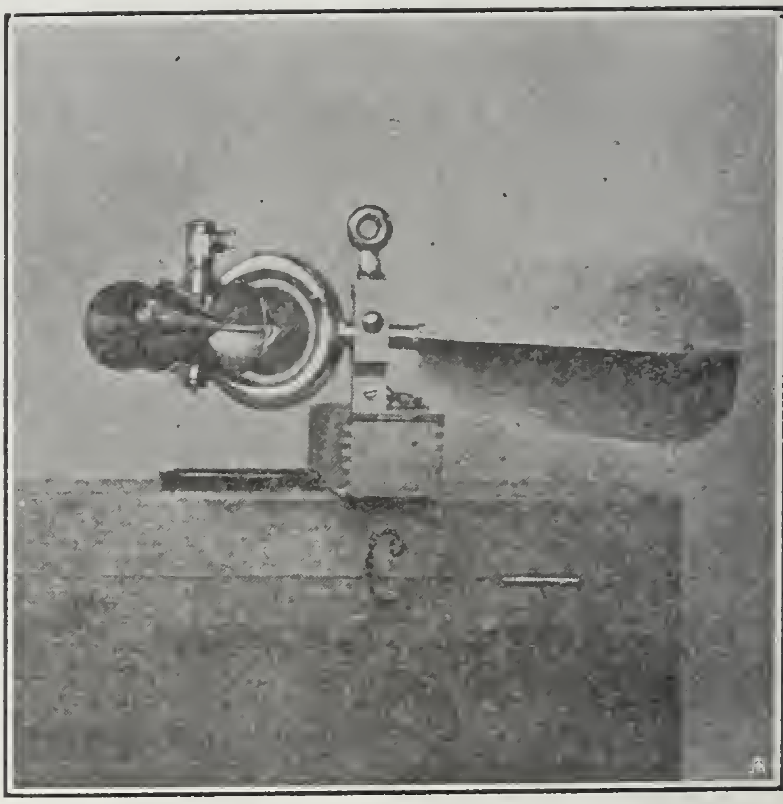


Fig. 45. Current Meter.

This meter was revolved similarly about a horizontal axis, readings being taken every 5-degrees up to 90 degrees above and below normal. As this instrument is generally used the investigation was carried further to show the effect of horizontal angularities on a rigidly supported meter. The former readings are shown in Fig. 46, by crosses (curve F) and the latter readings by circles (curve B). The light curves A and E are respectively the 100 percent circle and the true component circle previously mentioned.

Pitot tube readings were taken as before but the meter was so much smaller in proportion to the flow area that no difference could be distinguished in velocity for the entire range of meter position. On this account the tube readings are omitted so as not to complicate the figure.

Inspection of Fig. 46 shows that this particular form of cup is of such design as to closely fulfill the conditions of Mr. Price's statement given above. In order to determine the extent to which "the current perturbations moving up and down in the vertical plane" offset the increase in meter reading due to horizontal perturbation a method was used as follows:

From the general form of curves F and B, Fig. 46, it is evident that they most closely follow the equation of an elipse, the intersection of the axes of which lies at O. The curve must pass thru 100 hence the only unknown in the equation is the semi minor axis.

In order to determine the most probable curve the method of least squares was resorted to. The basic equation in polar coordinates, is

$$\frac{(r\ cos\ a)^2}{100^2} + \frac{(r\ sin\ a)^2}{b^2} = 1$$

Actually this should be in the form representing an ellipsoid of revolution but it is equally accurate and much more simple to work in a single plane, in which b alone is unknown. Multiplying the equation thru by the coefficient of b substituting the functions of the various angles 5°, 10°, 15° etc. up to 45° together with the corresponding vectors taken from curves F and B we arrive at a series of equations of one unknown. Adding all these equations together and solving for b, we find the probable semi minor axis to be 70.7. The curve or ellipse plotted on this basis is shown as C, Fig. 46. Inspection shows it to be a fair average between F and B from which it is derived. Only the readings up to 45° are used to determine it as this range probably covers the majority of flow conditions in which meters are used.

As a check on the accuracy of the method the summation was completed from 0 to 45° and from 0 to 20° separately. The two summations checked very closely in fixing the value of b, but the figure given above was obtained by adding the 45° value to twice the 20° value and dividing by 3, as a 20° variation is a more common limit in good measuring sections.

Curve C is of little value except that it is shown to lie close to the ideal E. To show this more closely, the above equation was rewritten to place the center of the theoretical

ellipse coincident with that of circle *E*. The determination made on this basis gave a semi axis of 52.8, the ellipse being shown as *D*. If this semi-axis were 50, the conclusion that curve *F* exactly offsets *B* for this velocity (4 ft. per second), would be

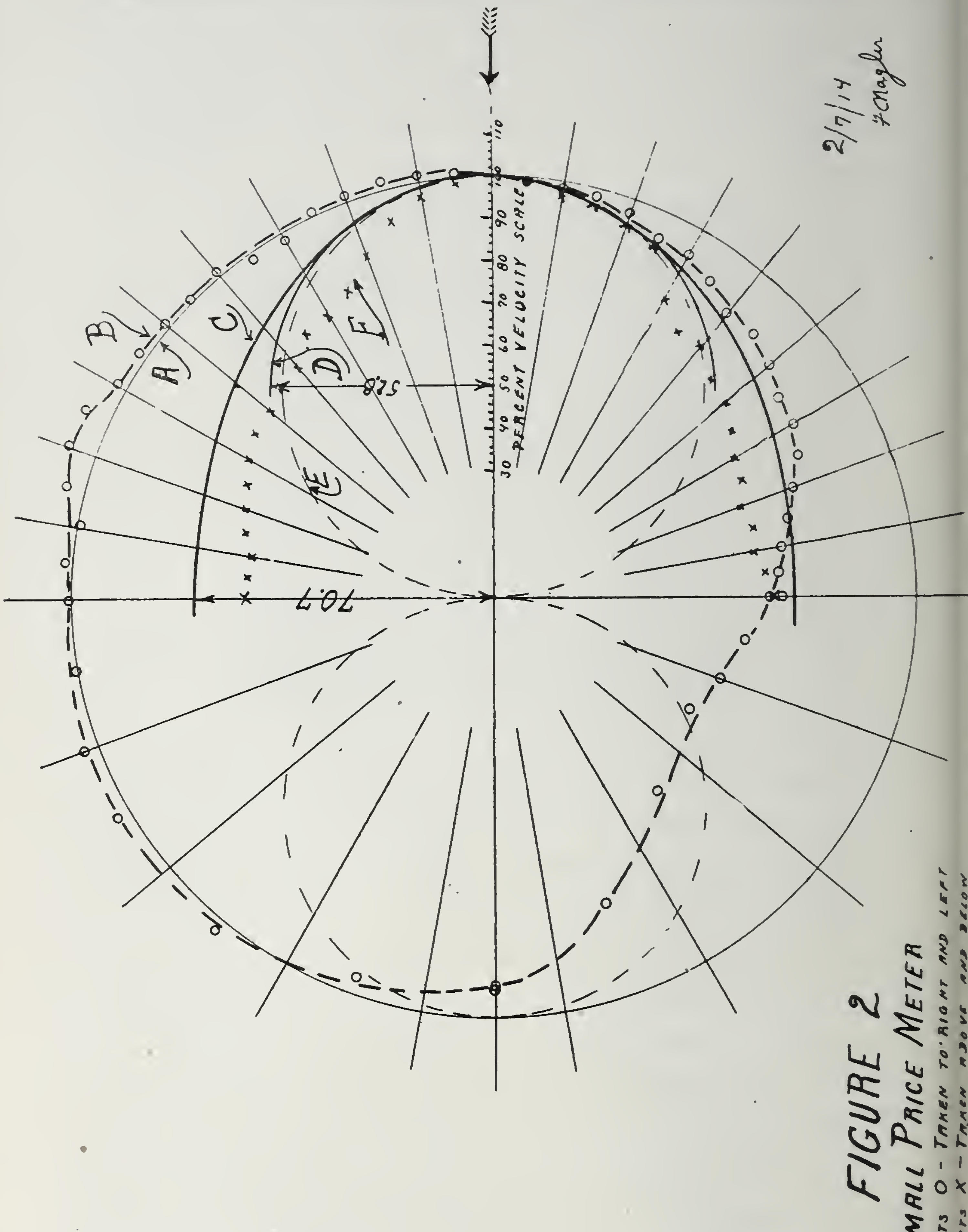


FIGURE 2
SMALL PRICE METER
POINTS O - TAKEN TO RIGHT AND LEFT
POINTS X - TAKEN ABOVE AND BELOW

justified. It is noted that the two curves *D* and *C* practically coincide up to angularities of about 25°.

From the above it is evident that the modern small Price cup type meter when rigidly supported is remarkably accurate in giving resultant components of velocities when subjected to flow that is disturbed uniformly in all directions. It is equally evident that a preponderance of angularity in any one direction horizontally or vertically will cause respectively an over-registering or an under registering.. Considering that horizontal disturbances are ordinarily caused by sides of channels and vertical disturbances, if any, result from inequalities along the bottom, it becomes evident why the small Price meter, when rigidly supported, registers an excess velocity. This is particularly true in turbine work where the measuring section is selected upstream from the turbine and adjacent to the entrance to the channel. The effect of the bottom is usually slight while there is a decided swirl or contraction around the upstream edges of the side walls or piers. As these walls are vertical the resulting angularities of flow are in a horizontal direction and produce the over-registering effect shown in curve *B*, Fig. 46.

The general conclusion may be drawn from the above that even the best cup type of meter should preferably be used swinging free and never rigidly supported unless it was known that disturbances were uniformly distributed in all directions, a condition that can hardly be fulfilled in practical work. Further the large Price meter should always be used swinging free and either pattern will always register excess velocity when so supported, this excess depending on the degree of disturbance. It is to be noted in this connection that the curves of Fig. 44 and Fig. 46 show only the effect of angular flow and do not allow for the additional excess registered by a swinging meter due to the fact that it has imparted to it more or less side motion. This occurs in actual use in disturbed water by reason of the location of the meter head at a considerable distance from the axis of support.

On the basis of the above work the writer's conclusion is as follows:

The ideal meter is one which, when rigidly supported in

disturbed water will register only true components of velocity when subject to flow from any direction. This means it must have identical vertical and horizontal characteristic curves, both of which correspond to curve *E*, Fig. 46. To permit of this it is evident that the axis of rotation must coincide with the normal direction of flow. This condition at once limits us to the screw type of meter, the design of the head of which shall be such as to give the desired true components.

MR. ROBERT LINTON:‡ As bearing on the question of the relative accuracy of the Pitot tube and current meter, I have among my notes some flow records that were called to my attention several years ago. These measurements were made in connection with a test on a high duty pump used to supply an irrigation system in Texas. A detailed account of them is given in the Transactions of the American Society of Mechanical Engineers, (vol. 28, 1907, Test of a Rotary Pump by W. B. Gregory) but they may be sufficiently interesting to allude to briefly again.

The Pitot tube measurements were taken at 18 different points, as shown by the circles in the sketch, Fig. 47. The traverse of the current meter was as shown by the heavy dotted lines. It will be noted that the measurements thus taken cover, quite accurately, identical sections of the stream flowing in the flume. The current meter used was a No. 31 Gurley.

Nine measurements were made with the current meter, the instrument being passed slowly from one end of the path (indicated by the dotted line) to the other, the average length of time consumed being five minutes. Twelve measurements were made with the Pitot tube. The measurements were taken alternately with each type of instrument. The average flow indicated by the Pitot tube was 152.79 cu. ft. per sec. and by the current meter 152.99 cu. ft. per sec. The average flow indicated by the pump displacement, during the same periods, was 152.92 and 152.90 cu. ft. per sec., respectively.

Assuming that the flow was constant it would appear that quite a high accuracy is attainable with either method. The results emphasize the importance of taking the measurements in such a way as to secure, as nearly as possible, an average

‡Mining Engineer, Pittsburgh.

cross section of the stream, and indicate that with properly calibrated instruments, the accuracy of the results is directly dependent on using such an average cross-section. In the discussion of this paper Mr. Gregory stated that it seemed to him probable that both the Pitot tube and current meter were correct within 1.5 percent.

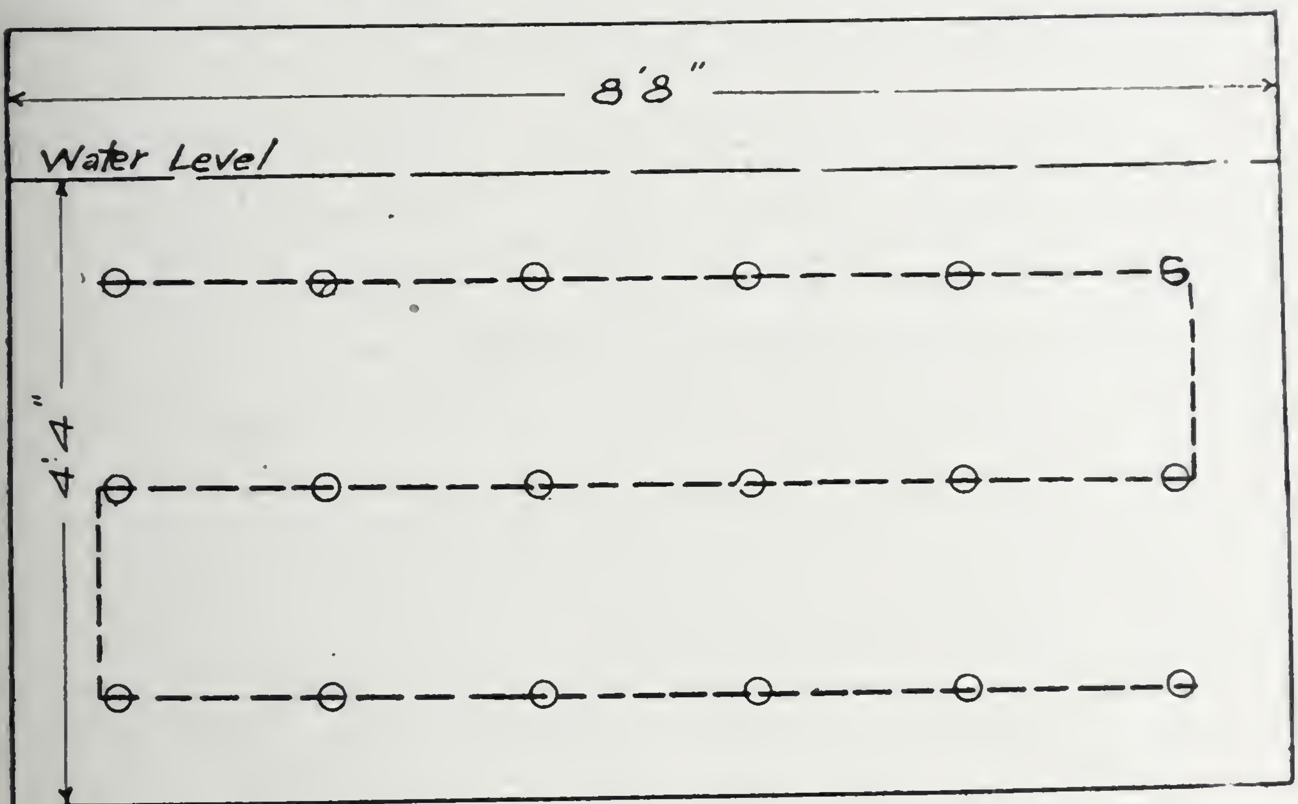


Fig. 47. Line of Traverse of Current Meter.

There was very little variation in the rate of flow, and as the flume was built of ¼ in. steel, it would be so smooth as to reduce friction to the minimum. These conditions would naturally facilitate accuracy in the measurements.

Mr. Herman Bacharach:* The very excellent papers of the evening have given us valuable information in regard to the measurement of the flow of water by means of Pitot tubes. Nothing has been said of the measuring of flow of gases by means of Pitot tubes and, therefore, I take liberty to say a few words on this feature.

Since the subject of measuring gas by means of Pitot tubes is so exceedingly large, I shall not go into detailed description of the principle and design of the Pitot tube, but shall speak shortly on the practical application of the Pitot tube and the recording device for measuring the velocity obtained with same.

*Mechanical Engineer, Hartje Building, Pittsburgh.

At some future date, I hope opportunity will offer itself to go deeper into this subject.

In scientific treatises one often finds the statement that Pitot tubes must be shaped to certain exact dimensions in order to obtain reliable results. While this is true for scientific tests, I am of the opinion that too much importance is laid upon this, and the man who could make good use of the tube in practice is prejudiced against it from the beginning.

AIR VELOCITY IN METER-SEC.	SHORT TUBE	MEDIUM TUBE	POINTED TUBE	LONG TUBE WITH FUNNEL	TUBE WITH DISC
	IN MILLIMETER-WATER GAUGE				
2.29	0.342	0.342	0.342	0.342	0.342
2.76	0.460	0.490	0.504	0.494	0.507
3.23	0.660	0.690	0.714	0.680	0.686
3.68	0.860	0.910	0.920	0.910	0.890
4.13	1.070	1.130	1.150	1.120	1.123
4.57	1.290	1.350	1.370	1.370	1.379
4.94	1.530	1.570	1.600	1.590	1.615
5.27	1.740	1.810	1.810	1.810	1.838
5.65	1.980	2.050	2.060	2.080	2.118
6.20	2.350	2.450	2.410	2.420	2.540
6.64	2.650	2.770	2.770	2.770	2.780
6.97	3.000	3.150	3.150	3.150	[illegible]

TEST MADE BY SER

Fig. 48.

The table of velocities herewith, see Fig. 48, gives the results of tests made with various shaped tubes. From this you can see that the results obtained with the different types show little variation. The greatest difference is shown by the short tube.

Pitot tubes have found much favor in Europe but Venturi tubes seem to have been used to a greater extent in the United

States. However, careful tests have proven that the accuracy of the Pitot tubes cannot be questioned, and their popularity is bound to increase.

The Pitot tube is very easy to install. If the measurements are to be taken in a pipe line, it is a simple matter to bore a hole in the pipe and insert the tube without interruption to the gas flow. For testing purposes, the device itself is very convenient for this reason. It can be easily removed and the tubes at all times kept clean.

It is very essential to have the Pitot tubes so constructed that they are easily installed and will always give good service. In practice, we often have to deal with unclean gas. The Pitot tubes should be so built that all clogging can be prevented. I shall now speak of some tubes which are designed to fulfill this demand.

The Pitot tube shown on Fig. 49 is mostly used. The static plus dynamic pressure, $p + c\,h$, is transmitted through the inner tube while through the small round openings the static pressure, p, only is transmitted. The following formula is used in connection with this tube:

$$(p + c\,h) - p = c\,h = \frac{v^2}{2\,g}\ s$$

in which

p = static pressure	h = dynamic pressure
c = coefficient	v = velocity of gas
= 1.0	s = specific gravity of gas

A modification of the above Pitot tube is shown in Fig. 50. It is designed for measuring gases of a temperature above 1000 deg. Fahr. The static and dynamic pressure is transmitted through a silica tube while the static pressure alone is transmitted through the annular space. The above formula holds good also for this tube.

The Pitot tube shown in Fig. 51 is very adaptable for measuring unwashed gas and gas of low velocity. It consists of two tubes, one with its opening facing the current, static plus dynamic pressure $p + c\,h$, and the other with an opening in the direction of the flow, static minus dynamic pressure $p - c_1\,h$. From this the following formula can be derived:

$$h_1 = (p + c\,h) - (p - c_1 h) = 1.37\,h = 1.37\,\frac{v^2}{2g}\,s$$

in which

$$c = 1.0 \text{ and } c_1 = 0.37$$

This formula shows that this Pitot tube magnifies the actual dynamic pressure 37 percent.

It will be seen from the figures that it is possible to slide the Pitot tube across a diameter of the main gas pipe and in this way get readings at an indefinite number of points along the diameter to determine the mean velocity of the gas.

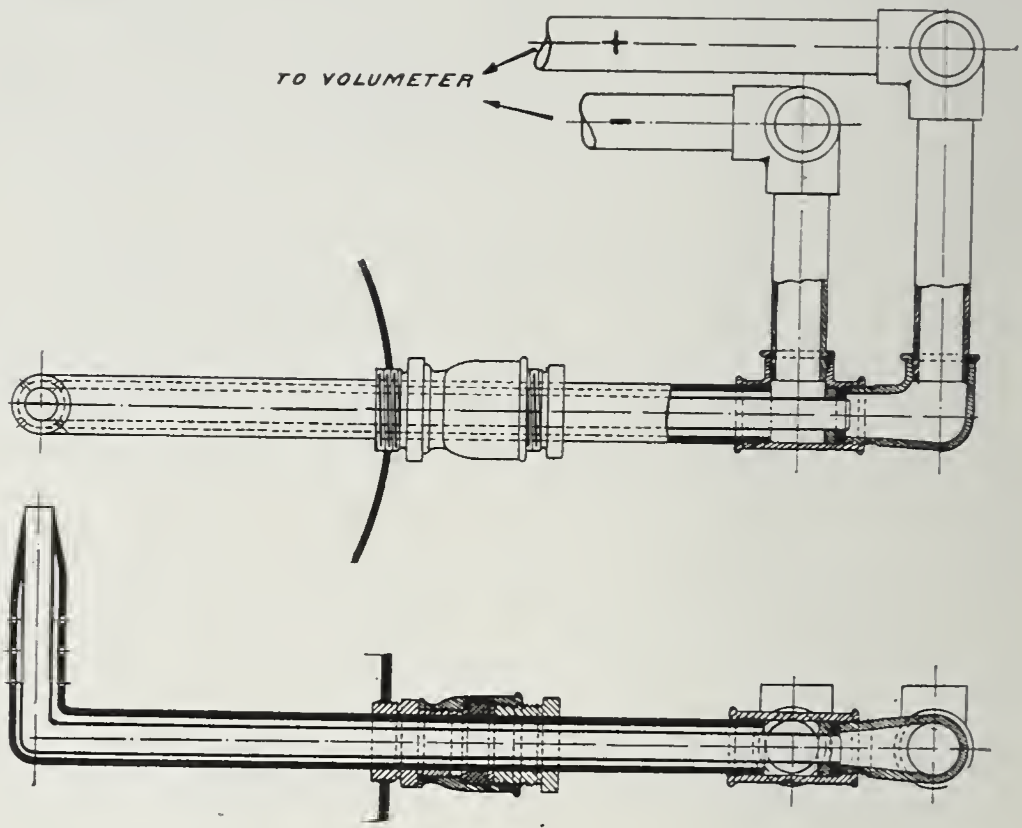


Fig. 49.

While the primary device, the Pitot tube proper, is of great importance, the device for indicating or recording the dynamic pressure is of no less importance. Such an instrument should be rigid; should need but little attention to keep it in working order; and its readings should be reliable at all times. Racks, pinions, stuffing boxes, and magnifying levers are entirely avoided in the instrument shown in Fig. 52, though magnification of the reading is almost limitless, in some cases being as high as 50 times.

This instrument consists of a cylindrical vessel partly filled with water. Into this water is immersed a hollow bell carrying a float. The interior of the vessel is shut off from atmospheric

pressure by means of a cylindrical cover, which is water sealed.

Communication to the outside of the tank is effected through two pipes. One pipe leads through the side of the vessel and has its opening under the bell. The other pipe has its opening in the section above the bell. The other ends of the two pipes are connected to the device producing the differential pressure; the pipe giving the higher pressure opening below the bell. It will be seen that the movement of the bell will depend on the pressure difference above and below it.

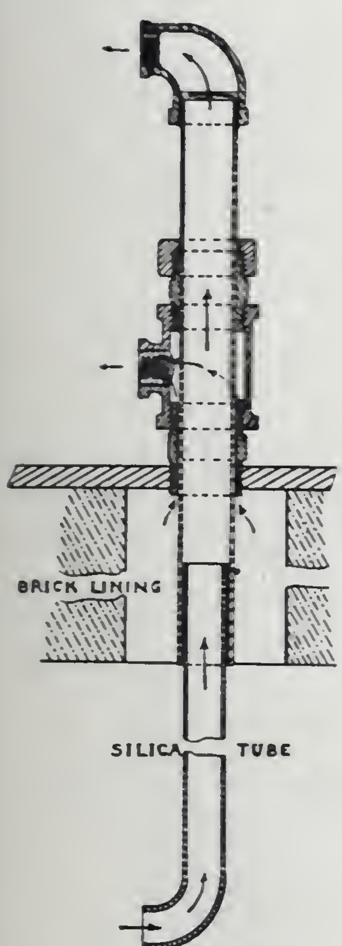


Fig. 50.

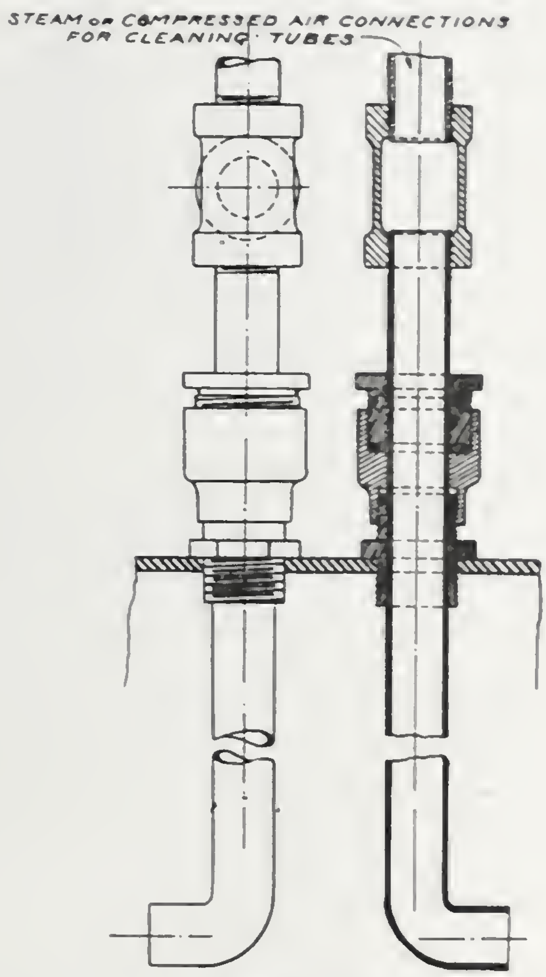


Fig. 51.

The motion of the bell is carried to the outside drum through a small rod. This rod is encased in a small tube leading from the outside of the vessel and ending under water, again making use of the water sealing principle for bringing the movement to the outside of the instrument. A pen is attached to the end of the rod and the vertical motion of the bell is recorded on the drum located at the top of the vessel.

There are two valves in the pipes connected by a single lever so that both sides of the bell can be put into communication with the pressure simultaneously. A small valve is located

so that the interior of the instrument can be placed under atmospheric pressure by opening this valve.

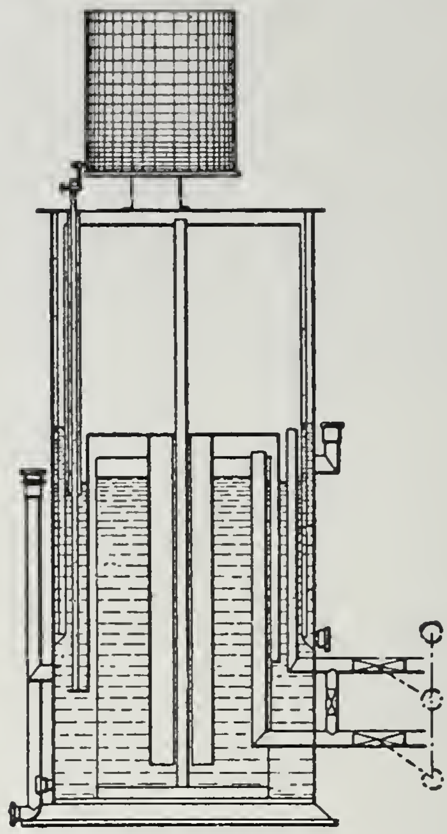


Fig. 52.

There is a general belief that reliable results are hardly obtainable since the devices are difficult to keep in good working condition for any length of time. My practical experience in this line has shown me that this is not correct. I know of many plants where Pitot tubes with recorders have been in continuous operation for several years with practically no repair, and are giving as good and reliable rseults today as when first installed.

Mr. W. M. White:* The Society is to be congratulated upon securing two such interesting papers upon this important subject by two such eminent hydraulicians. The subject matter of these papers is in harmony with the keynote of my engineering experience. Fourteen years ago I was confronted with the problem of measuring a large quantity of water for the determination of the efficiency of a centrifugal pump. The only possible means of measuring this quantity appeared to be by the Pitot tube, on account of the arrangement of the discharge from the pump.

Upon reading the literature on the subject, I found a dis-

*Manager and Chief Engineer, Hydraulic Department, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

agreement as to the formula to be used, some authorities claiming the correct formula as

$$h = \frac{v^2}{2g}$$

and other equally eminent authorities claiming the formula as

$$h = \frac{v^2}{g}$$

The matter of the formula seemed to be fundamental and it occurred to me to determine for myself the true relation between the head and the velocity.

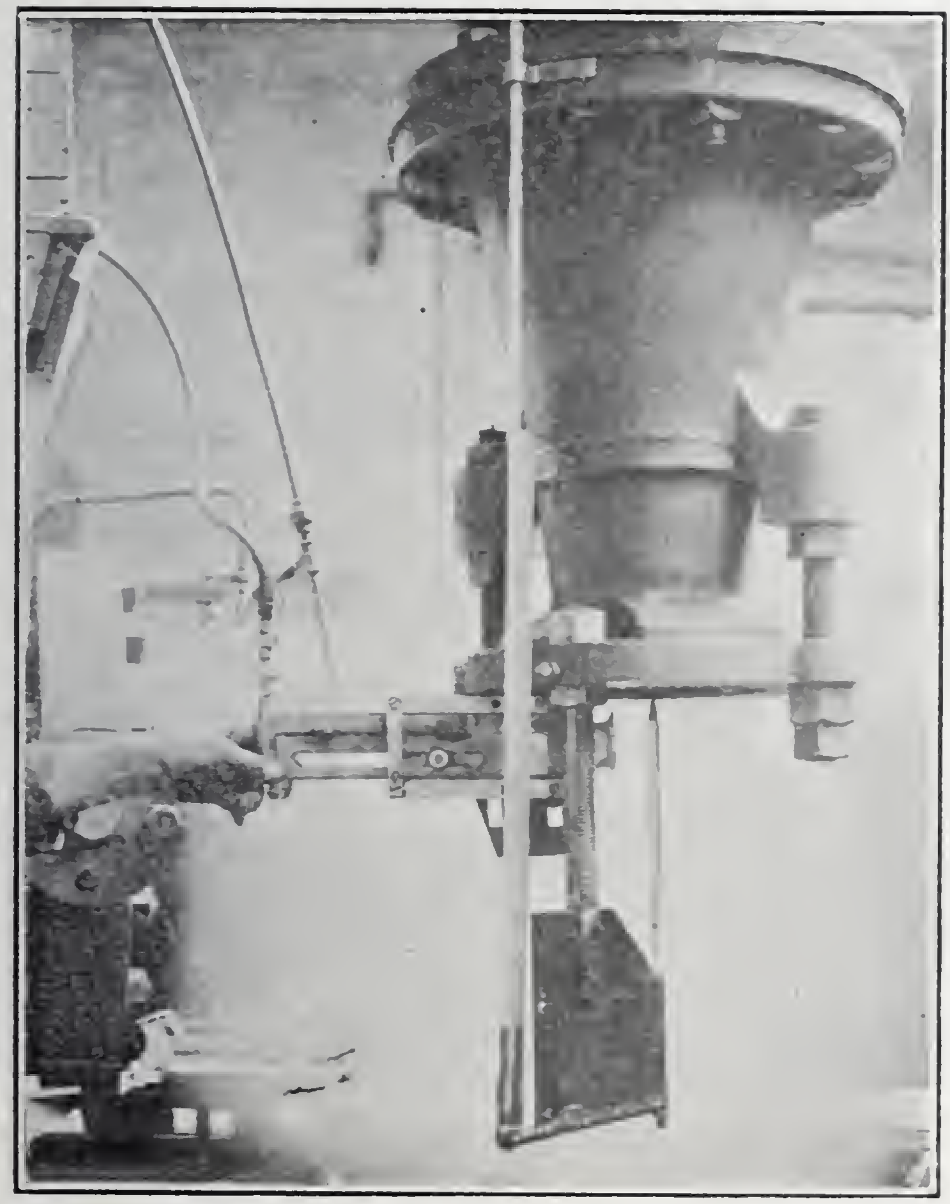


Fig. 53. Apparatus for Determining Pressure across diameter of a Jet at high velocity.

The simple apparatus used to settle, at least to my mind, this questions was:

A large box, an orifice in the bottom of the box centrally located.

Means of supplying a steady flow of water into the box.

Baffles in the box and over the orifice to prevent eddies, and cross currents causing a disturbance of the jet flowing from the orifice.

A glass gauge located upon the side and connecting to the box indicating the water level in the box.

An impact pipe located in the jet below the box.

A pipe leading to a gauge glass alongside of the one connecting to the box.

Four Pitot tube points of different shapes: sharp pointed, blunt point, flat and funnel shape.

The sharp pointed Pitot tube did not materially disturb the jet; the blunt pointed split the jet into a funnel shape, the sides of the funnel extending down; the flat plate deflected the

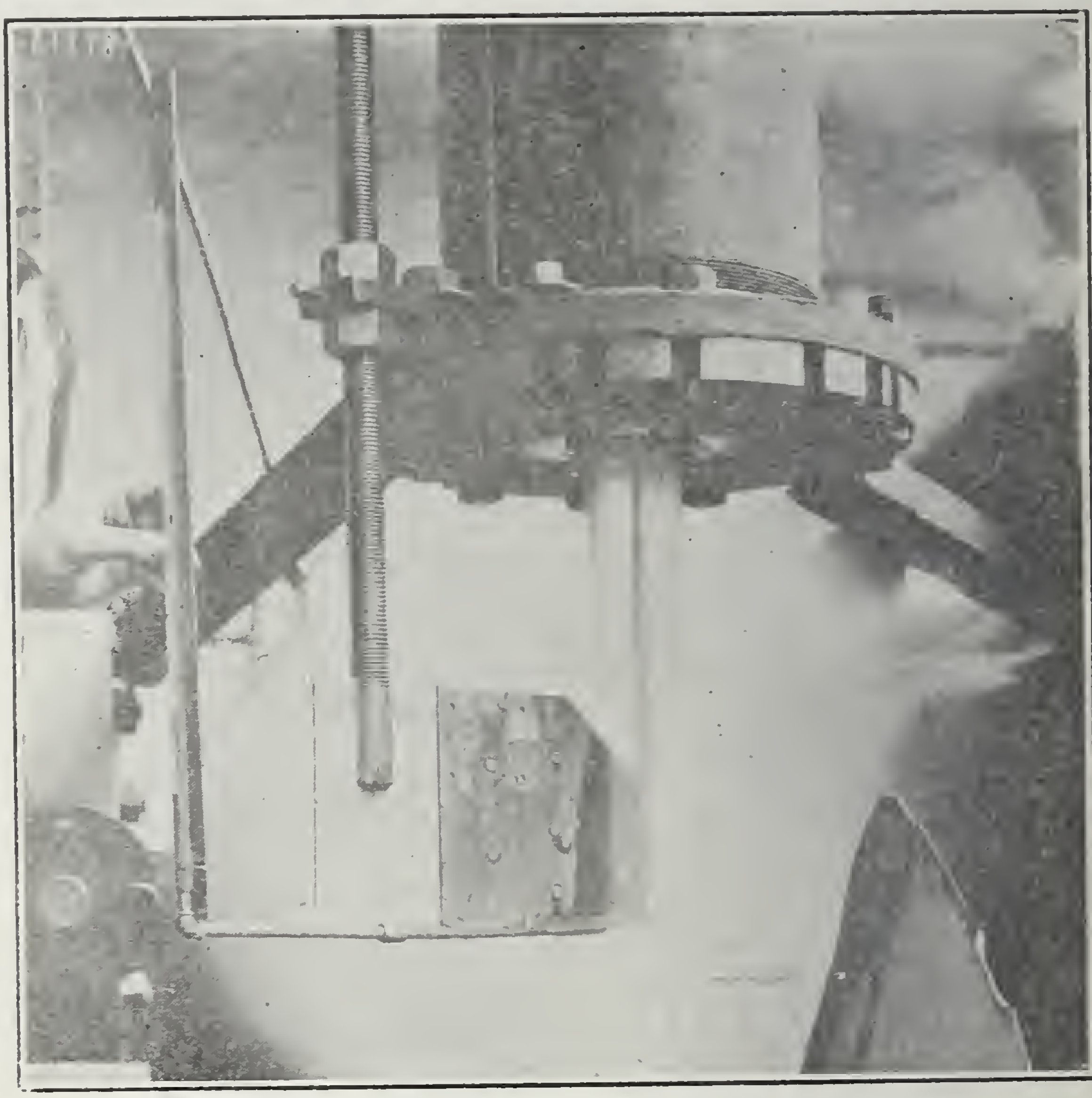


Fig. 54. Apparatus for Measuring Static Pressure in a free Stream.

jet from downward to ninety degrees in all directions; the funnel shape point deflected the jet into a funnel shape with the sides extending upward. No matter which one of the above tubes was used, nor through what angle the jet was deflected the pressure within the impact pipe as shown by the level of the water in the glass gauge, was always equal to the level of the water in the box, allowance being made for the loss of velocity

in the jet due to air friction. The impact pipe was raised and lowered producing less and greater velocities respectively, but the four Pitot Tube Points mentioned above always transformed velocity into pressure in accordance with the formula

$$h = \frac{v^2}{2g}$$

Further experiments were made by moving the four Pitot tube points in a canal of still water and it was noted that the pressure in the impact pipes leading from these Pitot tube points caused the water in all cases to rise to an equal level above the surface of the water in the canal.

Having settled in my own mind that the formula

$$h = \frac{v^2}{2g}$$

was correct for the point of the Pitot tube, I then found it necessary to devise a means of getting the true pressure in the water at or near the point of the Pitot tube in order to determine the increase of pressure in the impact pipe caused by the velocity striking the Pitot tube point over the static pressure in the pipe. I found that by sharpening a small rod, drilling a small hole at right angles to its surface some distance from the point connecting these cross holes to the center of the pipe and to gauges for determining the pressure and by placing this pointed rod exactly in line with the stream flow, that one could read the true static pressure in the water at that point. By combining any one of the Pitot tube points outlined above and this static pipe, I secured a Pitot tube which, when placed in undisturbed water flowing in parallel stream lines, would give the true velocity when the readings between the Pitot tube and the pressure were reduced, in accordance with the formula

$$h = \frac{v^2}{2g}$$

During the test of the pump referred to above I used piezometer openings in the side of the discharge pipe in a plane at right angles to the pipe and passing through the Pitot tube point to give the static pressure within the pipe, as well as using the sharp pointed rod described above. I found that the velocity at the center of the pipe did not produce a lower pres-

sure than existed at the sides of the pipe; in other words, the pressure in the water formed in a pipe measured along a diameter of the pipe remains the same even though the velocity at the center of the pipe is much greater than that at the sides.

I do not agree with Mr. Gardner S. Williams when he makes the statement that the pressure in the water measured along the diameter of the pipe is not the same but varies in accordance with Bernoulli's Law. It seems to the writer that this is not a

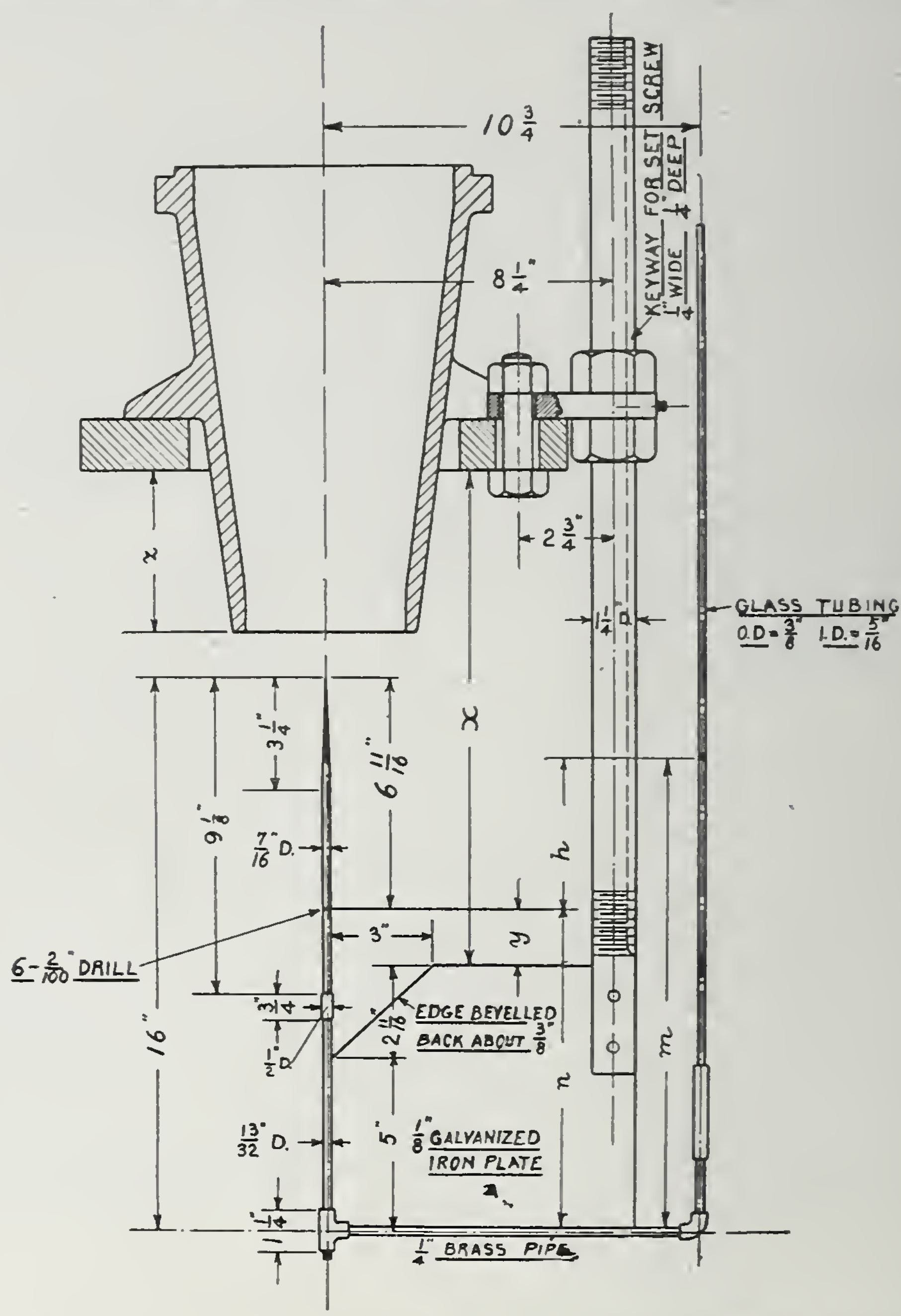


Fig. 55. Apparatus for Measuring static Head in a Jet.

case of the application of Bernoulli's theorem. As stated above all experiments which the writer has made confirm his opinion that the pressure across a diameter is the same. Mr. Williams has contended that the reason why a pointed rod or plate with piezometer openings does not show less pressure at the center of the pipe where the velocity is high is because the velocity of

the water along the rod or plate is reduced by friction until the velocity at the piezometer openings of this sharpened rod or plate is the same as the velocity near the walls of the pipe, where one would ordinarily measure the static pressure within the pipe, and consequently in accordance with Bernoulli's theorem the pressures would be the same.

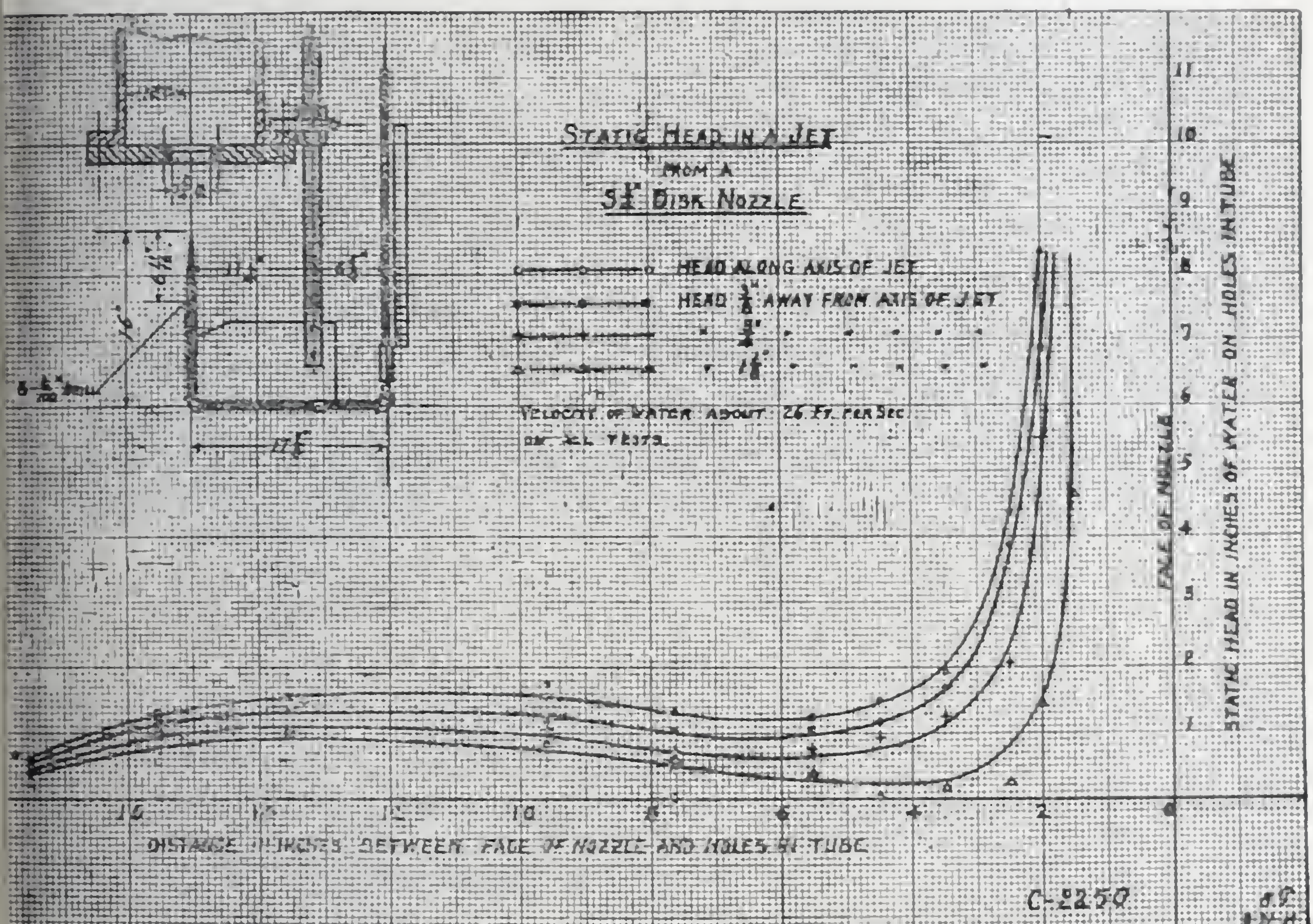


Fig. 56. Static Head in Jet from a 3¾ inch Disk Nozzle.

This is a very ingenious contention advanced by Mr. Williams and deserves our every consideration. The papers of Messrs. Moody and Groat are so thorough that I do not believe there will be any further questions as to the formula of the Pitot tube point. It is to be hoped that all hydraulicians may soon reach an agreement upon this point raised by Mr. Williams.

In an attempt to settle this point, I offer the results of the following simple experiments which have been made since the reading of Messrs. Moody's and Groat's papers and were made for the purpose of submitting in this discussion.

Rather than describe the apparatus, I will refer to Figs. 53 and 54.

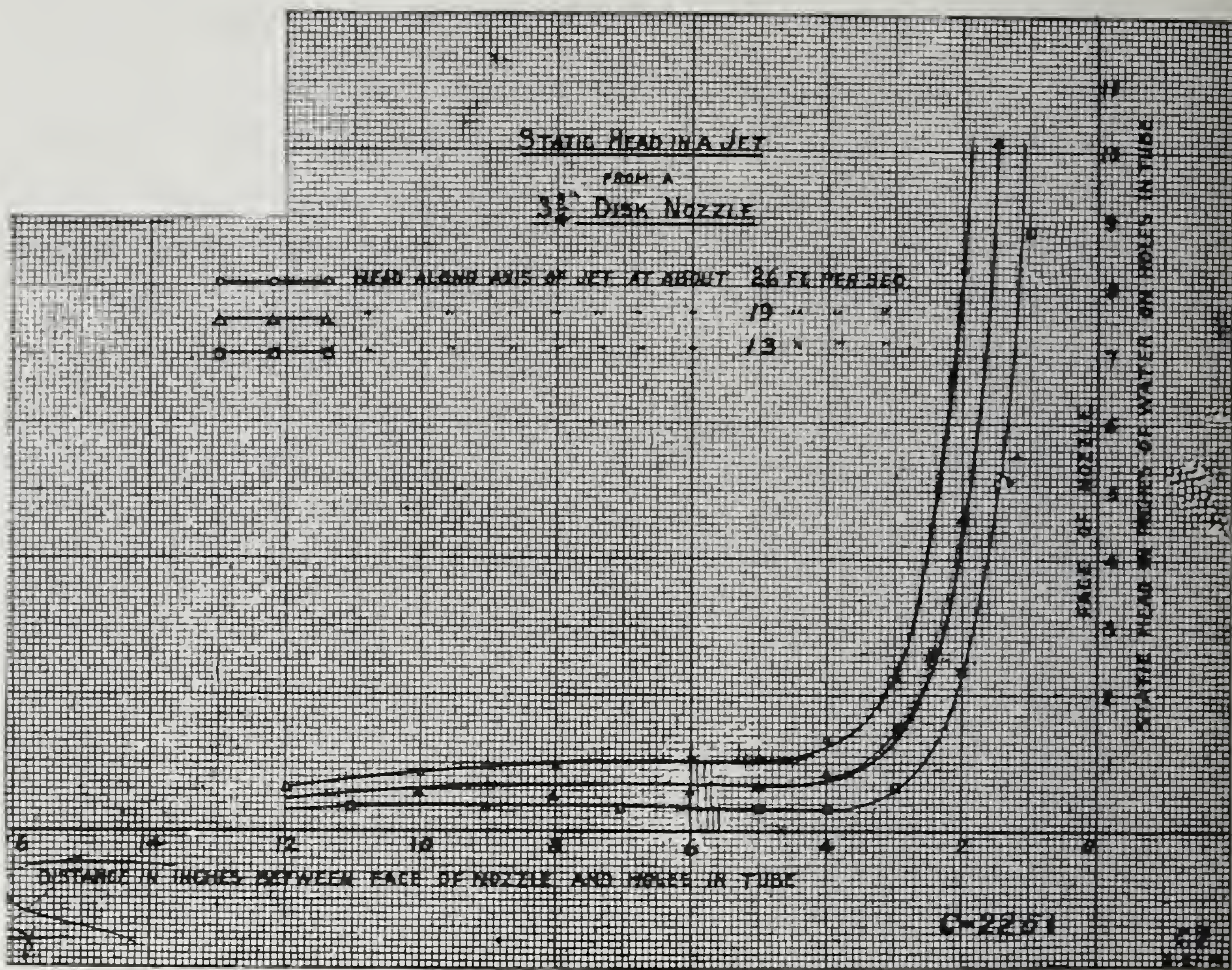


Fig. 57. Static Head in Jet from a 3¾ inch Disk Nozzle.

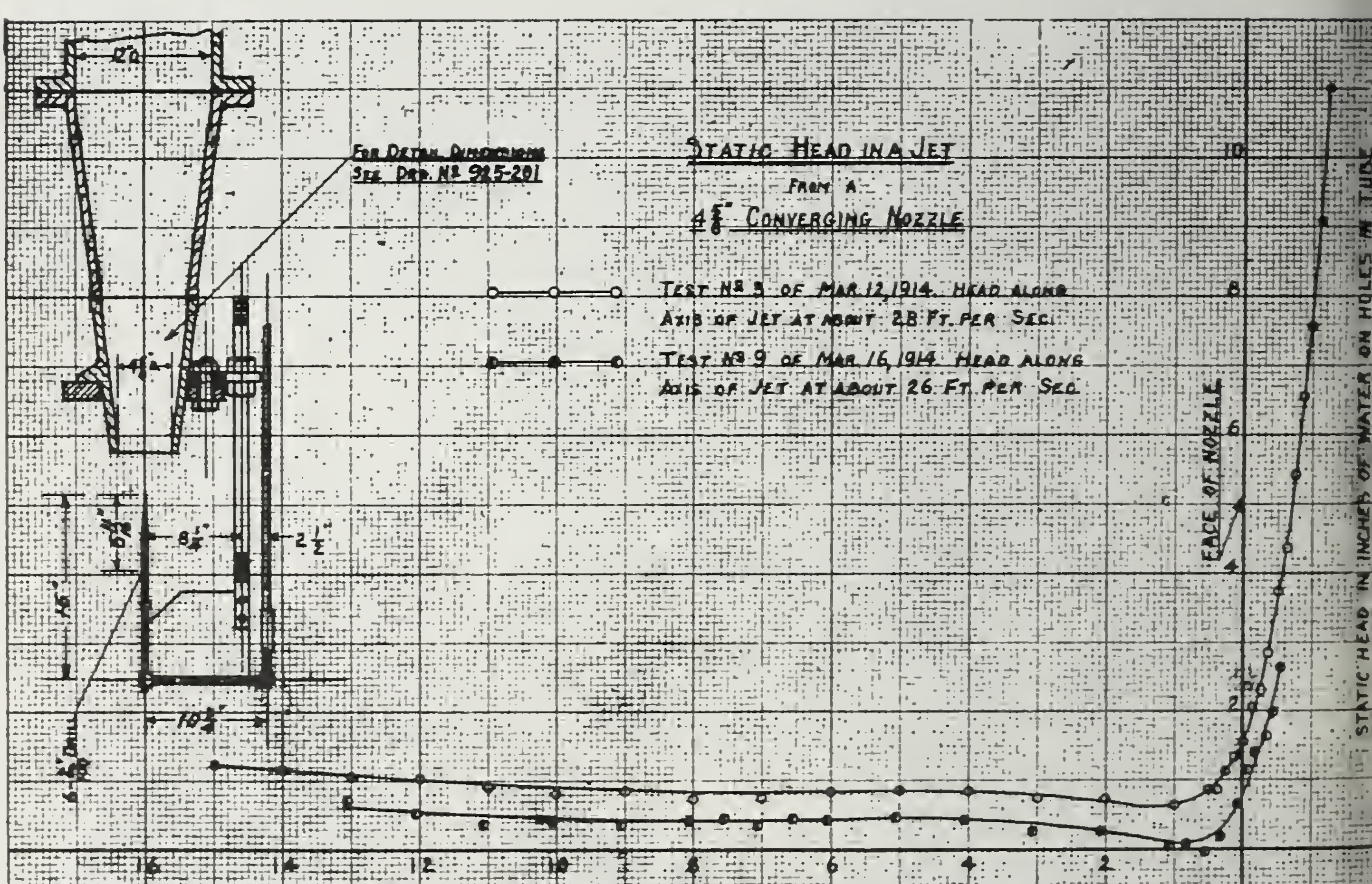


Fig. 58. Static Head in Jet from a 4⅝ inch Converging Nozzle.

In Fig. 53 provision is made for discharging a 4⅝ in. jet of water with a velocity as high as 30 ft. per second, the discharge taking place vertically downward.

In apparatus as shown in Fig. 54 provision is made to discharge a jet of water at various velocities as high as 30 feet per second through 3¾ in. disc nozzle. A sharpened rod $\frac{7}{16}$ in. dia., shown on Fig. 55, having holes about two hundredths of an

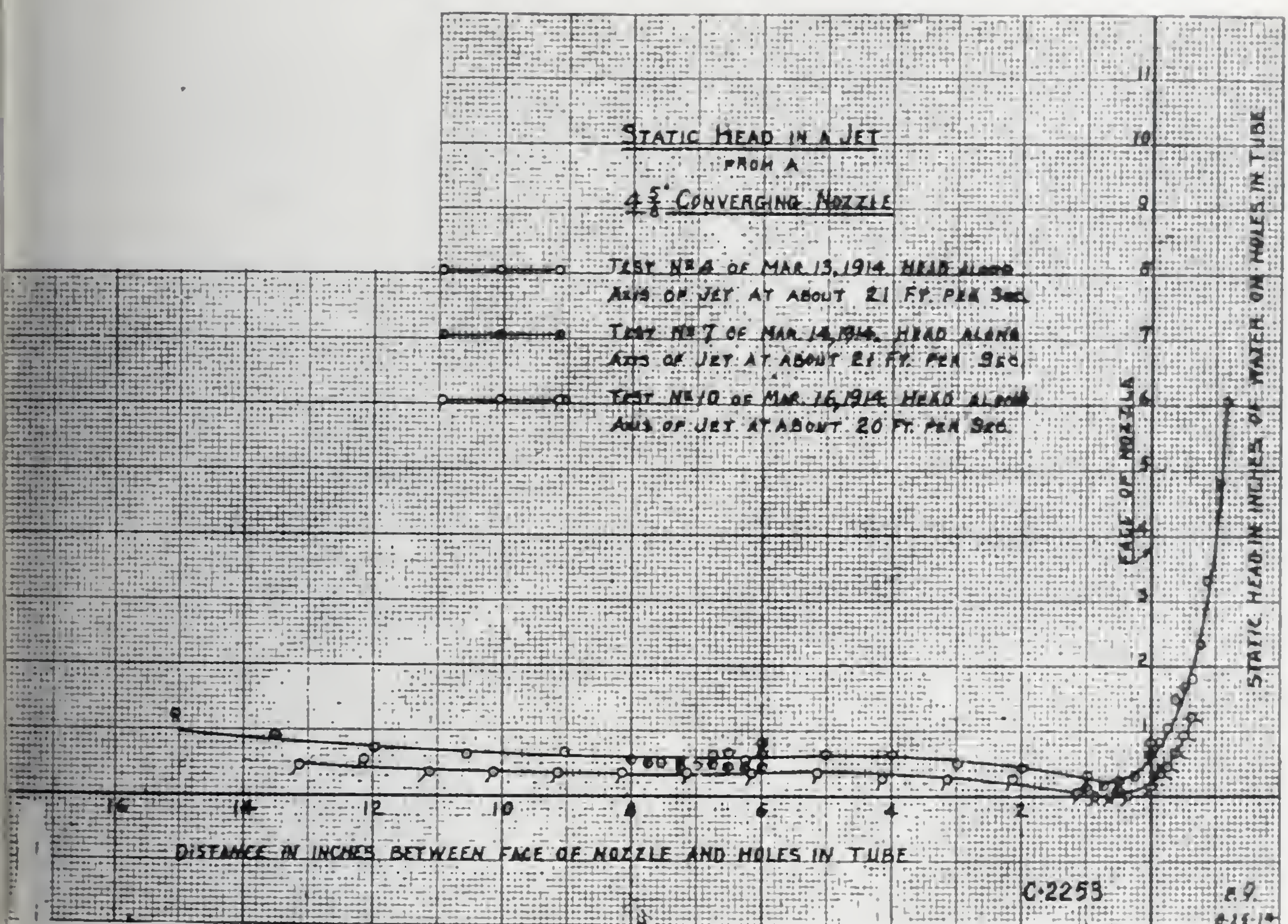


Fig. 59. Static Head in Jet from a 4⅝ inch Converging Nozzle.

inch in dia. drilled about seven inches back from the point, is held in the stream. These piezometer openings are connected by piping and glass tubing, as indicated in the cut. The sharpened rod is held and adjusted in the stream by a threaded rod, as shown to the left of the sharpened rod in Figs. 53 and 54.

The object of these experiments was to determine the pressure within a jet of water at high velocity and more particularly to determine whether the velocity along the sharpened rod at the piezometer holes affected the pressure reading at that point. It would seem that if Mr. Williams' contention is correct, we should obtain a different pressure reading when we change the velocity on the sharpened rod at the piezometer opening relative

to the velocity of the jet. I believe I obtained this relative change of velocity at the piezometer openings by moving the point of the sharpened rod up into the nozzle so that a portion of the rod was in an area of low velocity; therefore, the velocity of the water on the rod at the piezometer opening should be different on account of the loss of friction along the rod from the point to the piezometer openings now having been changed.

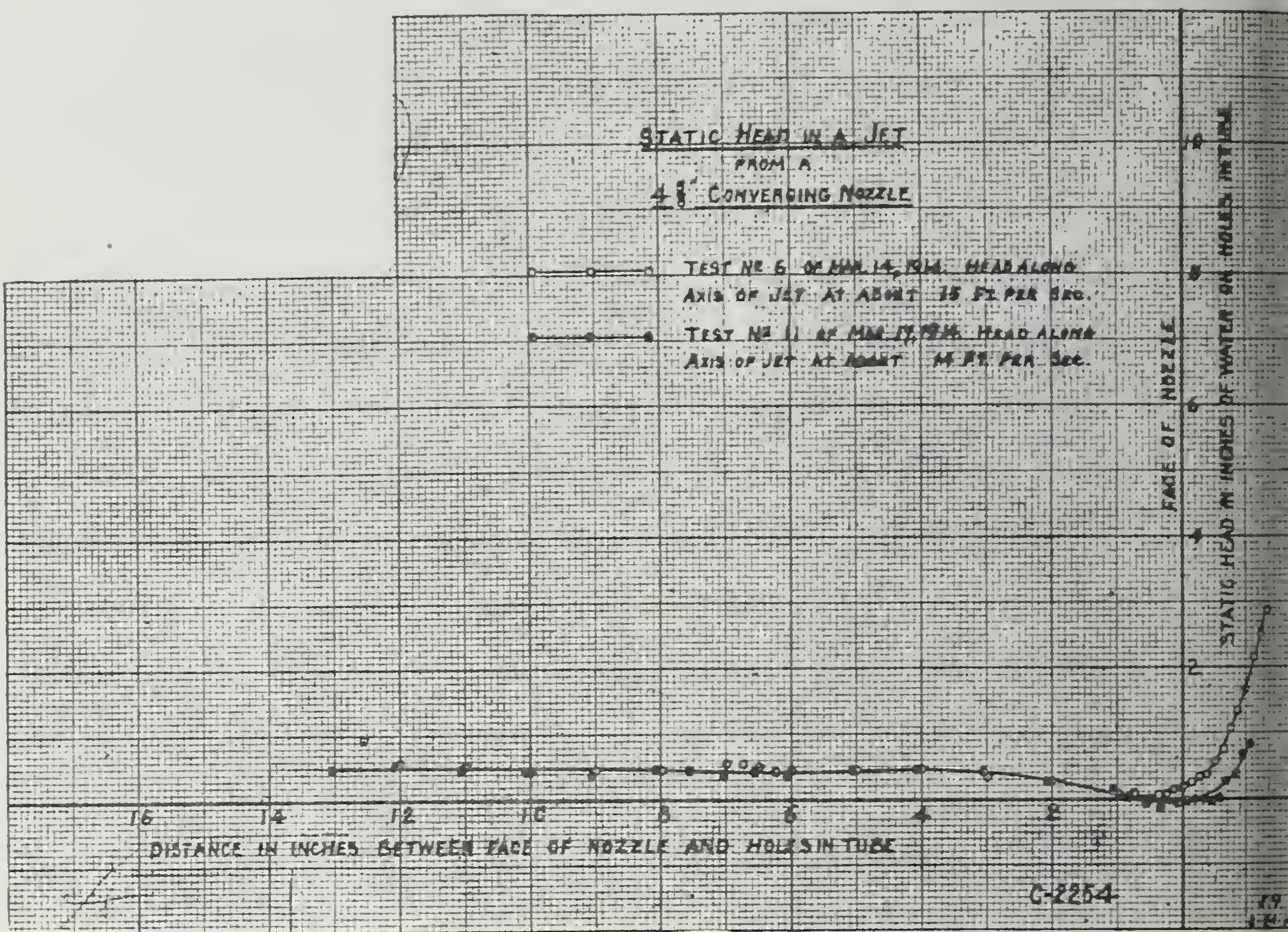


Fig. 60. Static Head in Jet from a 4⅝ inch Converging Nozzle.

The piezometer openings in the sharpened rod were placed in various positions with reference to the face of the nozzle and in some instances allowed to pass beyond the face of the nozzle into the pipe itself. In no instance, however, was there a result obtained which would justify Mr. Williams' contention. Attention is called to the fact that the plottings as shown in the illustrations are made to "inches of water", whereas actual velocity head of the jet in some instances was as high as 40 feet.

Figure 56 would seem to indicate a slight difference in pressure between the center of the jet and its outer edges. We may be reasonably sure, however. that the velocity was the same

across the jet as a traverse made by the small Pitot tube, Fig. 53, showed the same velocities across the jet.

Figure 57 shows the pressure under varying velocities and Fig. 58 shows the pressure in the jet issuing from a 4⅝ in. diameter converging nozzle.

It will be noted that in Figs. 58, 59, 60 and 61 the pressure in the water dropped to atmospheric just at the edge of the nozzle. I cannot account for the increase of pressure in the jet after it has left the nozzle, unless it be surface tension on the jet,

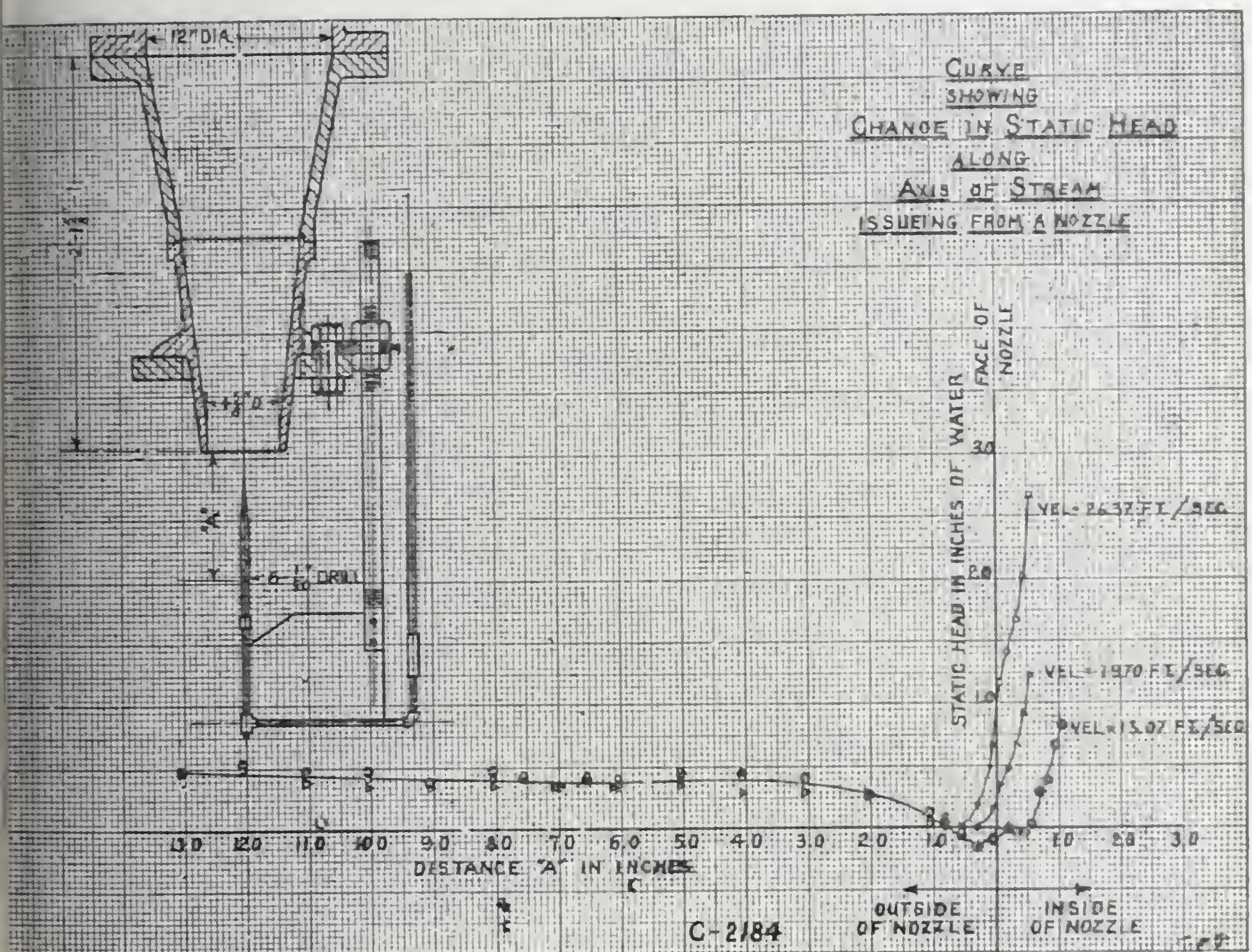


Fig. 61. Curve showing Change in static Head along Axis of Stream issuing from a Nozzle.

or particles of air being released from the water after sudden decrease of pressure, and this air tending to shove out the sides of the jet, thereby producing a slight pressure at the center.

From these illustrations it is evident that there is no drop in pressure due to the high velocity, and certainly no such drop as would lead one to believe Bernoulli's theorem could be applied in determining the pressure across a diameter of a pipe filled with flowing water.

The above data is presented without full analysis but it seemed advisable to at least give the illustrations here in order that they may be recorded with the other matter on the subject of the Pitot tube.

Mr. J. N. Chester:* These papers have been to me extremely interesting, and to the best of my knowledge give for the first time, in print, the development of the formulas governing Pitot tube measurements, but I have been struck most forcibly by the claims made for the accuracy of this type of measurement, wherein one of the speakers recites his efforts to ascertain by Pitot tube measurement the efficiency of turbines to within a small fraction of one percent, which is an attempted precision far beyond what I had ever hoped for or presumed such a form of measurement capable of producing.

While I agree with one of the authors in his statement "that the Pitot tube is, perhaps, capable of more general application than any other form of velocity measurement and furnishes one of the most useful tools which the engineer can command," yet I cannot agree as aforesaid with his ideas of the accuracy of such instruments; for as he says, water flowing in a pipe or channel does not move in smooth streams, nor does the velocity at any given point remain constant, but is full of local whirls and vortices.

One picture thrown on the screen, during the delivery of the papers referred to, illustrated a large penstock wherein, in order that the Pitot tube could reach the middle of same and also across for the traverse, the photograph shows that it became necessary to insert, just back of the tube, a frame work which must naturally set up the eddies above referred to, and how an accuracy of measurement within one percent under such conditions can be expected is more than I can conceive.

In my own practice where I have had opportunities of calibrating such instruments, I have always been well content to find them within one or two percent, and I do not feel that the usefulness of this instrument is in the least impaired by the fact that no greater accuracy can be attained for it.

*Consulting Engineer, Chester and Fleming, Sanitary Engineers, Union Bank Building, Pittsburgh.

PROF. LEWIS F. MOODY:* The mass of material collected in this discussion is so extensive that the writer cannot attempt to give adequate consideration to the great number of points which deserve comment. Contributions from authorities on the particular subjects treated have been presented by Mr. Clemens Herschel, on the Venturi meter; Dr. N. C. Grover, on the current meter; Mr. Edward S. Cole on the Pitometer; much interesting and valuable data has been furnished by Prof. Chas. M. Allen on the rating of Pitot tubes; Messrs. E. H. Brown and F. Nagler on the characteristics of the cup type of current meter; Mr. Robert Linton on comparative measurements by Pitot tube and current meter; Mr. Herman Bacharach on the use of the Pitot tube with gases. Mr. Thomas P. Roberts has recounted some notable experiences in the measurement of river discharge and has discussed the rationality of the Pitot tube in principle. The discussions of Messrs. Morris Knowles, Wm. Kent, Gardner Williams, Wm. M. White; and the initial papers of Mr. Groat and the writer, all refer mainly to the Pitot tube and the hydraulic laws involved in its action.

Several of the discussions have opened up questions involving some of the most fundamental laws of hydraulics. The divergent views held by many engineers in regard to some of these questions present a curious situation, the explanation of which may lie in the fact that many of the phenomena of hydraulics, while apparently simple are really complex, and the further fact that our present knowledge of hydraulics is largely empirical and is not held together by an adequate and systematic theory. Considering, for instance, certain contentions advanced by Mr. Williams in his notable discussion, which it will be well to take up first, it should be remembered that while the same views are held by some other engineers, there are also advocates of the opposite conclusions. These differences are so radical that it is important for us to give them careful consideration. I may say at the outset that I am strongly of the opinion that certain of these contentions are wrong; but when they are advanced by an engineer of Mr. Williams' standing, the matter is made doubly difficult.

Mr. Williams refers to the theory of the Pitot tube, as applied to the measurement of pipe discharge, given by him in

*Authors Closure.

the *American Civil Engineer's Pocketbook.* This theory is based on the assumption that water flowing in a straight uniform pipe is subject to a considerable variation in static pressure at different points in a transverse section, so that the pressure at the center of the pipe is materially different from the pressure at the pipe walls. I have heard this proposition advanced by some other engineers; and have also known other advocates of Mr. Williams' second assumption, namely: that the amount of variations of the pressure at any two points of a cross section can be calculated by saying that the pressure head plus the velocity head at one point is equal to the pressure head plus velocity head at any other point, a so-called application of the Bernoulli theorem. My own position is that while a difference between the pressures at center and wall of a pipe is conceivable if there exists an axial rotation of the water in the pipe; still, I hold that even if such a difference exists, there is no basis either in theory or fact for assuming the magnitudes of the pressures to be connected by the above relation.

It is probable that irregularities, such as bends, in a pipe may set up a certain amount of rotation of the stream about the pipe axis; but in a long straight pipe such rotation would be soon destroyed by friction. It is possible that a slight rotation in the immediate neighborhood of the pipe axis may persist in the straight pipe; (See Prazil "Hydrodynamik") but there is no experimental evidence of any appreciable amount of rotation. Such rotation would, of course, involve centrifugal forces which would reduce the pressure at the axis and raise the pressure at the pipe wall; but it is readily established by turning a Pitot tube at different inclinations in a pipe that the tube gives its maximum reading when parallel to the pipe axis, thus indicating that there is no persistent whirl or rotation.

With water flowing without a rotation of the stream as a whole although subject to local disturbances, the following considerations are of interest. The late Professor Spangler of the University of Pennsylvania used to teach that if water flowing in a straight, uniform pipe or channel were subject to pressure of different intensity at the center and periphery of a given transverse section of the stream, the necessary result would be a flow from the high point to the low. Since a continuous flow

from the walls of the pipe toward the center would have to be neutralized by an equal flow of the displaced water from the center to the walls, no such inequality of pressure could remain permanent.

Some experimenters have apparently detected variations of pressure across a pipe, as in the tests described by Mr. Williams. This result may be accounted for by the difficulty in obtaining reliable instruments to record the static pressure in a moving stream, as will be explained.

I would like to quote from a letter referring to this subject written by Mr. H. Birchard Taylor*, in reply to a communication from another engineer describing the results of tests made with a piezometer placed at different positions in a pipe, similar to the experiment of Mr. Williams:

"Tests were made some years ago by the Mississippi River Commission in connection with hydraulic dredges, in which traverses across a section of a pipe by means of a piezometer were made and checked against piezometer readings secured by tapping into the sides of the pipe. There were found to agree exactly."

"We have also had occasion to make traverses by means of Pitot tubes in a pipe in the laboratory at the University of Pennsylvania, where it was possible to actually weigh the water flowing in automatic weighing tanks as a check against the Pitot tube. The quantity of water flowing in the pipe as determined by the Pitot tube agreed almost exactly with that determined by the weighing tanks. If the pressure had been less in the center of the pipe than at the walls of the pipe, there would have been a discrepancy in these two results."

"I believe that the whole proposition, as far as the experimental side is concerned, depends upon the form of the piezometer used in the traverses. If the piezometer is such as to create an eddy, such eddy acting on the piezometer opening, a suction action will occur at the opening, which action will be greater, the greater the velocity. Therefore, as we approach the axis of the pipe from the outside and encounter increasingly higher velocities, this suction would gradually increase and the tests would apparently indicate that the pressure is lower in the center of the pipe than that at the periphery."

"We all know that most of the early tests with Pitot tubes were made with the static opening located on some part of the instrument making the traverse, rather than on the wall of the pipe. Results taken with tubes of this form were so incorrect and variable that careful investigation was made by a number of engineers to determine the reason for this condition. This investigation resulted in the discovery

*Hydraulic Engineer of the I. P. Morris Co., Philadelphia, Pa.

of the fact that the Pitot tube proper, which reads the pressure head plus the velocity head, was of such a form as to create a disturbance in the water, and that this disturbance was felt at the static or pressure opening."

The Mississippi River Commission tests referred to are described in Reports of Efficiency Tests of Hydraulic Dredges, (1903), as follows:

"Tube No. 9 was then inserted into the same vertical section as the piezometer and with the point of the tube at the center of the pipe. The static side was in turn connected with each piezometer through a differential gauge and in no case could any difference of pressure be observed. The pressure given by the four piezometers and the static side of the tube was exactly the same."

"This experiment, with some others taken with the point of the tube at different points along the diameter of the pipe, shows incidentally that the pressure is the same throughout any section across a pipe and that the Bernoulli theory is not true when applied to a section."—From report of F. B. Maltby.

"It was also shown that the pressure, obtained by means of a piezometer at the outside of a straight pipe in which water is flowing is precisely the pressure of the entire cross section of the pipe, corrected, of course, by height of point considered; and that it agreed exactly with the static side of a properly constructed Pitot tube at that section. That in a straight pipe a Pitot tube can be used with impact opening only and static pressure obtained by means of a carefully inserted piezometer at outside of pipe, is thus clearly shown."—From report of W. B. Gregory.

In an article† by Prof. A. H. Gibson of Manchester, which has appeared since the papers under discussion were presented, are the following:

"Where the Pitot tube is to be used for pipe flow some observers have used a plain impact tube for the velocity head, taking the pressure from an orifice in the wall of the pipe itself in the plane of the impact orifice."

"In the case of a smooth straight pipe there is little, if any, direct experimental evidence as to the variation of pressure across a diameter. If any such differences exist they must, however, be extremely small, and such impact tubes as have been used in this manner have in general shown values of C sensibly equal to unity.* For small pipes of smooth bore this method of measuring pressure is preferable to any other.

†The Development and Theory of the Pitot Tube, The Engineer, (London), July 10, 1914, page 29; and July 17th, page 59.

*C, in the formula $v = C\sqrt{2gh}$.

Whether an appreciable pressure variation exists or not, it is difficult to conceive of this variation reaching the amount required by the relation assumed by Mr. Williams. If the velocity adjacent to the pipe wall is one-half that at the center, which is a fair approximation in most cases, then the velocity head at the wall is one-quarter of that at the center; and the pressure would have to vary to the extent of three-quarters of the velocity head at the center of the pipe, or more than the head corresponding to the mean velocity.

More important than any of the above considerations, however, is the question: Is it correct to equate the sum of the velocity and pressure heads at one point in a stream to the sum of the velocity and pressure heads at another point? This is presented as an application of the Bernoulli theorem; so that it will be well to investigate this claim.

My conception of the Bernoulli theorem is that it is the application to hydraulics of the law of conservation of energy and nothing more. The total energy contained by the water flowing past a given section of a stream is given by the sum of the velocity, pressure and elevation heads multiplied by the weight of water passing the section. When the same water reaches another section of the stream, it will have lost a certain amount of energy which has been dissipated in heat, or lost in what we call friction. Then we can write

$$W\left(\frac{v_1^2}{2g} + hp_1 + z_1 - h_L\right) = W\left(\frac{v_2^2}{2g} + hp_2 + z_2\right)$$

in which h_L is the head lost by the water in flowing from the first to the second section. As originally proposed by Bernoulli, the h_L term was absent, and the formula was applicable to a perfect fluid only; but in the above form it is applicable to actual and not merely to ideal conditions.

If water enters a pipe from a reservoir in which the velocity is zero, the total initial energy contained by each unit weight of water is given by the elevation of the water surface in the reservoir; and if there were no loss of energy, as is imagined in the case of the perfect fluid, all particles would contain equal energies at all parts of the stream and we could apply the Bernoulli formula with the h_L term omitted between any two particles, in

relative positions either up and down or across the stream—or, if all particles should suffer the same loss of energy before reaching a given transverse section, then we could again apply the same form of the theorem between particles at various points in the section, such as at the center and ends of a diameter of the pipe. Both of these cases, however, represent imaginary and not actual conditions.

Every particle of water is actually losing energy as it flows along a channel, due to impact and rubbing on neighboring particles. This loss arises primarily from the tangential "frictional" resistance between the column of water filling the pipe and the pipe wall. If all the water in the pipe were to flow at the same velocity, the column would advance as a solid, and all the loss of energy would be confined to the particles in contact with the wall. Actually, however, the outer particles are retarded and rub on the neighboring particles nearer the axis. The outermost particles continually receive energy from the portion of the stream nearer the axis, this energy keeping them in motion in spite of the resistance of the wall. The energy which is transmitted to the outermost particles is lost by the particles nearer the axis, which in turn receive energy from those next within; so that there is a continuous flow of energy from the center of the pipe toward the walls. The particles at the center of a given section have not yet lost as much energy as those near the walls, so that the velocity-head of the portion of the stream near the axis plus the pressure-head at that point is always greater than the velocity-head plus the pressure-head near the walls, instead of the two sums being equal.

That this deduction is actually as well as theoretically correct is convincingly demonstrated by placing a Pitot tube at different points in a transverse diameter of a pipe. Since the tube records the sum of the pressure and velocity heads, if this sum were constant across the pipe, the tube would show no variation; but as we know, the tube registers much greater values in the center than at the walls.

In the endeavor to obtain further experimental verification of the non-variation of pressure across a uniform pipe, (although the point seems to be well established), the writer has suggested the problem for laboratory experiments by students.

A number of designs of piezometer have been constructed and before applying them to the measurement of pressure in a pipe, the behavior of the piezometers themselves has been investigated. So far the results have been unsatisfactory, since no form of piezometer has been found which is sufficiently reliable for the purpose.

The investigation was made by inserting the instrument in an open jet, in the neighborhood of the "vena contracta" or slightly beyond, at a point where the flow lines are parallel and the pressure is atmospheric. Most of the instruments tried show a certain amount of "aspiration effect" or reduction of pressure due to the velocity of the water, as mentioned by Mr. Taylor in the passage quoted.

The best form of instrument is, perhaps, a flat plate held parallel to the current or a pointed cylinder with small pressure openings in the cylindrical portion. In order to keep the plate small enough to avoid distortion of the lines of flow in the pipe, the instrument is rendered sensitive to slight changes of direction; so that the pressure recorded is a better indication of the angle at which the plate is placed than it is of the actual static pressure. Perhaps the piezometer tube used by the Mississippi River Commission is as satisfactory as any.

The best form of piezometer utilizes the pipe wall itself as the guiding surface, the pressure being taken from orifices carefully drilled in the wall, as described in the original paper.

Even if a correct static piezometer is used, there will still be found a difference between the still-water and moving-water ratings of the Pitot tube, due to the turbulence in the water. The reason for this difference, the extent of it and the method of determining it, are the chief points discussed in the writer's paper; the paper, therefore, furnishes the explanation of Mr. Williams' first point, where he states that he has failed to obtain agreement between the two ratings. Mr. Williams' experiments, therefore, confirm the writer's conclusions, but not exactly for the reason he suggests.

The paper of Prof. Gibson gives further confirmation of this point:

"Without exception, observers have found that a still-water rating

gives the higher values of C*, indicating that with a given mean relative velocity of water and tube the pressure in the orifice is greatest when the water is in motion."

Mr. Williams' second point raises a question as to the accuracy obtainable with the Pitot tube. Mr. White has answered this point. The writer might call attention to the fact that all the refinements which have been applied to the method of using the tube have varied the coefficient from unity by so small a percentage that the instrument still furnishes an almost absolute means of measuring velocity. It is not necessary to *rate* Pitot tubes, because we now have sufficient knowledge to be able to estimate the corrections which must be applied without any further rating. Under stream-line flow conditions the coefficient is exactly unity; and with considerable amounts of turbulence the correction is within 3 percent. If, under usual conditions of pipe flow, a coefficient between 0.975 and 0.98 is chosen, it is unlikely that errors of one-half of one percent could exist. To quote again from Prof. Gibson:

"In the majority of cases a reduction of 3-percent in the true value of C would give fairly accurate results and where the instrument cannot be rated under conditions similar to those in which it is to be used, some such correction should be made."

Aside from the doubt—which may easily be expressed—regarding the accuracy of this method, the writer has been surprised at the reason which Mr. Williams gives for questioning the results. Mr. Williams says: "When we come to think that in gaugings by either of those devices (Pitot tube or current meter) there is occupied at the very best perhaps 10 percent of the area of the stream to measure its velocity, we are hardly warranted in saying that we know enough about the other 90 percent of the area to be within one percent of the actual discharge."

The curious aspect of this objection is that it will apply equally well to very nearly every sort of engineering measurement. How do we measure the output of an electrical generator? By taking wattmeter readings at intervals throughout a test, the actual time covered by a single reading being perhaps a second, while readings may be taken only once in from one to five

*C in the formula $v = C\sqrt{2gh}$.

minutes. Yet we are not surprised when the average of a number of such readings closely checks an integrating wattmeter determination covering the entire time. In testing a steam engine we may take indicator cards at intervals of 15 minutes, each card representing a fraction of a second of actual time; yet, if the load is reasonably steady, we would see no necessity for installing a continuous indicator to cover every instant of a test of long duration. In determining the heating value of a carload of coal, it is satisfactory to take samples representing points distributed throughout the mass. The amount of coal actually tested may be only a gram, but this will give us an accurate determination of the heating value without the necessity of burning the whole carload.

The objection quoted applies to any test in which we take instantaneous readings to represent performance over a period of time or in which analysis is made of samples to represent a mass; and almost the entire field of engineering testing is covered in just this way. When Pitot tube measurements are plotted in a curve and the curve is found to be smooth and continuous through all the points of measurement, is it a fact that the measurements represent only the area covered by the tip of the tube or do they give us a very reliable indication of what is happening over the entire section? There is small doubt that if we used many times the number of points, we should not alter the result. Actually, of course, we do not try to use a large Pitot tube covering a wide area, but we try to keep the tube within the smallest practical limits in order to avoid distortion of the flow which we wish to investigate.

I am glad that Mr. Williams has introduced these subjects for discussion, and I hope that the discussion will go far toward settling some of the mooted questions which have long troubled engineers. I am indebted to Mr. Williams for his endorsement of my main conclusions regarding the coefficient of the tube. In the brief but convincing discussion by Mr. Morris Knowles, we have valuable experimental data and well-founded theoretical explanations confirming some of the more important contentions of the writer. In view of the considerations advanced by Messrs. Groat, Knowles, Kent and White, as well as the authorities quoted above by the writer, and giving due attention to the

opposing views of Mr. Williams, it would seem that the main conclusions are well established. The hope expressed by Mr. White that the problem of the Pitot tube may at last be definitely settled certainly appear to be justified.

Mr. Kent asks on which side of the Pitot tube formula the coefficient used by the writer should appear. It is probable that this has not been clearly indicated in the typewritten form of the paper; but it will be evident that the formula should be

$$v = k \sqrt{2gh}$$

for turbulent water, k being less than unity under ordinary conditions. The explanation of the fact that the tube apparently reads more than the head corresponding to the velocity, as pointed out by Mr. Kent, is also given in the paper. The tube does not read more than the full oblique velocity impinging on it, but it registers enough of the oblique velocity to raise its recorded pressure above that which would be produced by only the normal component which we wish to measure.

Touching briefly on a few points in the various discussions, chosen more or less at random I note the following:

Referring again to the work of Mr. Knowles, I would call attention to his curve of velocities across a ½ in. jet at the contracted vein, under high heads. This curve is equivalent to that given by the writer for a 2½ in. jet under a low head, except that the latter curve is plotted on a distorted base scale—distances from the axis of the curve representing the squares of the corresponding distances in the jet—while Mr. Knowles' curve is drawn to natural scale. If the two curves are plotted in the same way and reduced to equivalent conditions, they would appear to be almost capable of being superposed. The portions of the curve near the sides are, of course, exaggerated in the writer's method of plotting. I do not quite follow the reason for Mr. Knowles having plotted the curve in inclined lines at each side, as if the velocity were zero at the surface of the jet. Of course, the Pitot tube will read less and less as it is withdrawn from the water; but the curves should, I think, have been drawn so as to intersect the end ordinates at a point above the base line. This is, however, a point of little significance and merely refers to the drawing of the curve.

Mr. Linton's comparison of measurements made by Pitot tube and current meter for determining pump discharges is interesting. The use of a single transverse with the instrument over a zigzag path covering the entire flume is open to some slight criticism when the greatest accuracy is required. since it is generally recognized as not giving as good a determination as either separate vertical traverses or point measurements.

The method shown mixes with the horizontal traverses portions of vertical traverses at points of low velocity at the sides of the channel. The better method permits the discharge to be obtained by planimeter from plotted curves of velocity which thus allows the variation of velocity to be taken into account by drawing smooth curves through the measured points. The results show that the current meter indicated slightly more quantity than the tube; and that they both fell slightly below the pump displacement. This would appear to indicate, if the meter was of the cup type, and if the pump displacement given is the gross amount not corrected for slip, that a small correction for pump slip would bring both results in close harmony with the papers under discussion.

Referring to the discussion presented by Mr. Herschel, the writer would like to state that he has great confidence in the Venturi meter when it is possible to apply it. The Venturi meter, like the Pitot tube, is based on a rational principle; and the experimental coefficient which must be used in connection with it is close to unity, this coefficient being in almost exact agreement with that used with the Pitot tube. There are doubtless many places where Venturi meters could be installed and where these would provide the simplest method of measurement, but there are many more cases where the conditions are such that it would be difficult or impossible to use them.

Few Venturi meters have been used in connection with hydraulic power plants, for instance. In considering the comparative merits of the Venturi meter and Pitot tube, it should be remembered that the installation of a Venturi meter in a penstock involves a certain loss of head. For example, in the Tallulah Falls plant of the Georgia Railway & Power Company, which is the only example which occurs to me where the Venturi meter has been used for this purpose, a rough calculation

shows that the meter should cause a loss of head amounting to more than a half of one percent of the effective head on the plant. Although this loss is small, it represents a loss of power which goes on day after day during the life of the plant.

A Pitot tube outfit may be installed for the time occupied by the tests and then removed, and at no time does it cause a loss of head which is capable of calculation. A slight additional expense involved in the Pitot tube method of test would be insignificant in comparison with the cost of power lost. The installation of a temporary Venturi meter would hardly appear to be practicable in the case of most large developments, and its cost would certainly be much in excess of that involved in the Pitot tube method.

I note Mr. Herschel's remark in connection with weir measurements that the Fteley & Stearns formula "asks the Engineer to add linear feet to cubic feet per second." This formula is in the form.

$$Q = 3.31\ L\ H^{\frac{3}{2}} + 0.007\ L$$

If the last term contained simply the symbol "L" without the coefficient, this criticism would be justified; but if the coefficient represents discharge per foot of crest, which it undoubtedly does, the above remark has no force.

In connection with the Pitot tube Mr. Herschel criticises the method of attempting to place the Pitot tube at a point in the pipe cross-section at which the velocity is the same as the mean velocity in the pipe. This criticism is a very proper one, and for the reason which he states this particular method of applying the Pitot tube has not been recommended by the writer and in fact, is not used in important measurements. Mr. Herschel states that "Ordinary Pitot tube or Pitometer gaugings are, therefore, approximations only." The same statement applies to any physical measurement.

In connection with the Venturi meter it may be said that Prof. Allen's use of Pitot tubes placed at the throat section of a Venturi meter is an interesting combination of the two methods and it would be desirable to see it further applied.

Referring to Mr. Cole's interesting discussion, the writer has always favored the use of a simple Pitot tube in preference

to the Pitometer for the reason that the simple tube used in connection with a reliable static piezometer approaches very closely to an absolute instrument, requiring no calibration and applicable with correction factors so near unity, that the field of possible error is quite narrow. The Pitot tube has the further advantage that the correction factors have been definitely determined, and the characteristics of the tube have been thoroughly investigated.

The reversed tube used with the Pitometer is open to suspicion. The writer considers it to be unreliable, particularly under low pressures, and has investigated its behavior in an open jet under atmospheric pressure. These tests showed that the reversed tube gave in various tests two distinct sets of coefficients, this change in the coefficient being produced by unknown causes, such as perhaps the entrapping of air in the low-pressure space behind the tube. In a pipe in which there exists a high vacuum it would be impossible for the reversed tube to show the same proportionate amount of reduction in pressure that it would record under ordinary conditions, since it would have to record pressures less than absolute zero. I would like to quote Prof. Gibson's remarks concerning the Pitometer arrangement:

"Although the increased head reading is an advantage, such tubes are not altogether successful. In the most favorable circumstances the negative head fluctuates within wide limits owing to the periodic growths and break away of eddies behind the tube, and the values of C obtained during a rating vary much more than in the more usual type of tube."

Owing to lack of more thorough knowledge of the details of the tests which Mr. Cole mentions, I am not able to analyze the results. Whether the agreement, within one percent, of the two measurements which were made under different conditions of turbulence or oblique flow was due to the obliquity being only sufficiently different in the two cases to call for a one percent variation, or to some other characteristic of the Pitometer which has tended to offset a wider divergence in results, I cannot say. I shall be glad to see further experimental investigation of this instrument.

In reading Professor Allen's discussion account should be

taken of the fact that the coefficient there referred to is that corresponding to the expression

$$h = c\frac{v^2}{2g}$$

This coefficient is, therefore, the square of the reciprocal of the coefficient appearing in the writer's paper, and C in Professor Gibson's paper quoted above. This brings Professor Allen in agreement with Professor Gibson and the writer when he states:

"From all of the experiments made in still water with the same instruments, the coefficients are higher in value in every case than with moving water ratings to the extent of from 3 to 5 percent."

These results would correspond to the coefficients of my paper being from 1½ to 2½ percent lower in running (turbulent) water than in still water. It may be safely assumed that there will be much less variation of the coefficient from unity when the tube is placed at the throat of a Venturi meter than when it is placed in a straight pipe.

The valuable investigation by Messrs. Brown and Nagler of the characteristics of the large and small types of Price meter are of great interest. They have brought out the fact that the large Price meter behaves even worse when subjected to velocities inclined in the vertical plane than it does under horizontal lateral velocities; this result was expected by the writer, but the extent of this peculiarity is surprising, and indicates that the large Price meter is a very unreliable instrument; the discontinuance of its use by the Geological Survey, as reported by Dr. Grover, is justified. The results reported by Messrs. Brown and Nagler in the case of the small Price meter are still more surprising, although the investigation has been made before. The following table I have computed from tests made by Mr. Rumpf and reported in his Thesis, and the results are in close accord with those of Messrs. Brown and Nagler. These were still-water ratings of the small Price meter inclined in the vertical plane, and each result represents the average of at least four runs:

Vertical Angles					Horizontal Angles	
Inclination of meter $= \theta$	Revolutions per foot	Coefficient $= \Phi = \frac{\text{rev. inclined}}{\text{rev. normal}}$	Cos θ	Ratio $\frac{\Phi}{\cos \theta}$	Φ	Ratio $\frac{\Phi}{\cos \theta}$
Normal position 0°	0.435	1.00	1.00	1.00	1.0	1.0
Inclined 8° 30′	0.4211	.968	.989	.979	1.0	1.011
Inclined 12°	0.4137	.952	.978	.973	1.0	1.023

In explanation of this table it may be said that if the meter is to read correctly, its revolutions in the inclined position should fall off in proportion to the cosine of the angle of inclination; at the two inclinations given its revolutions actually decrease in the ratios 0.968 and 0.952, which are 97.9 and 97.3 percent of what it ought to record; the effects of the vertical obliquities given are therefore to make the meter read 2.1 percent and 2.7 percent too low. Since the average effect of horizontal obliquities in both directions is not to reduce the revolutions at all, the effects of the same horizontal angles are to make the meter read too high by 1.1 percent and 2.3 percent respectively. The effect of turbulence on the small Price meter will, therefore, as mentioned by these investigators, be dependent on the prevalence of vertical or horizontal cross-currents or disturbances in the stream; so that while this meter is likely to give much better results than the large Price meter, its performance is still to a great extent problematical.

This discussion has already extended to such a length that it will be impossible to give due consideration to Mr. Groat's valuable paper; but the writer feels that little need be said in this connection on account of the substantial agreement of the two papers on all essential points. The writer believes Mr. Groat's derivation of the Pitot tube formula to be in full accord with his own. The recent paper by Prof. Gibson considers theoretically the case of a sharp-edged tube such as tubes "C" and (approximately) "D" of the writer's paper. The theoretic coefficient deducted by Gibson for this case is slightly less than unity in the formula

$$h = k \frac{v^2}{2g}$$

corresponding to a coefficient slightly greater than unity in the formula used by the writer. Referring to the results given for tubes "*C*" and "*D*" when held in the straight position, it will be seen that this conclusion is in agreement with the tests. The slight excess of the coefficient over unity was attributed to experimental inaccuracy; but this would indicate that the results are probably correct, and that a pointed tube reads slightly too low, when there is no turbulence.

The theory given by the writer applies properly to blunt-faced tubes or plates having a small hole or orifice; and in this case both theory and test prescribe a coefficient of unity, or the tube obeys the law $v = \sqrt{2gh}$ when the end of the tube is normal to the flow. Professor Gibson states in this connection that:

> "If a flat surface of the same area as the end of the impact tube be exposed to the normal impact of a current, the pressure at the center of its front face is undoubtedly equal to $v^2 \div 2g$. At this point the central filament divides, the velocity must be zero, and the pressure is in excess of that at a point where the velocity is v by an amount corresponding to the head equivalent of this velocity."

The experiment made by Professor A. M. Greene, Jr. and the writer at the Rensselaer Polytechnic Institute, referred to in the note on page 338 of Mr. Groat's paper, may be briefly described:

A long arm is mounted on a vertical shaft, which is driven through worm gearing by a motor, so that the arm rotates in a horizontal plane. The purpose of the apparatus is the calibration of anemometers; but provision has been made for attaching Pitot tubes to the end of the arm. The Pitot tube can thus be moved at high speeds in a circular path of large radius; the tube being subject to the impact of the air. The apparatus is somewhat similar to that used by Prof. Allen for ratings in water. The tube can be turned so that its face is normal to the direction of motion. The pressure produced in the Pitot tube is recorded by a sensitive fluid gauge of the inclined tube type, communicating with the tube by way of the hollow shaft and arm of the instrument. No stuffing-box is used, but a water seal is arranged so that leakage is entirely prevented. When the arm is rotated, the pressure recorded by the gauge is that produced by the Pitot tube minus the centrifugal pressure of the

column of air in the arm. The head corresponding to this centrifugal pressure amounts to

$$\frac{1}{2g}(v_1^2 - v_0^2)$$

in which v_1 is the velocity of the point of the tube and v_0 that of the inner end of the column where the pressure is taken off. In this case $v_0 = 0$.

It was found by experiment that when the Pitot tube was adjusted with its axis truly tangential to its path, the pressure recorded by the gauge was zero, showing that the tube gave sufficient pressure exactly to balance the centrifugal pressure; so that the head given by the tube is $v_1^2 \div 2g$. When the tube was turned at various angles, the pressure dropped off, and the gauge gave negative readings. The instrument can be used for quite high velocities and its pressure indications are sensitive to slight variations.

The above test therefore furnishes a good check on the Pitot tube formula.

The experiments at Massena described by Mr. Groat show that the Pitot tube is less affected by turbulence than either of the types of current meters used. Beyond this conclusion, the writer does not believe that any inferences regarding the exact coefficient of the tube should be drawn from the tests described. The method of taking readings of the Pitot tube pressures was criticised at the time of the tests, and while it seemed sufficiently reliable to indicate the form of the velocity curve of the stream in the neighborhood of the wall and bottom of the channel, which was the purpose intended, it certainly did not give evidence of securing an accurate discharge measurement. The extreme oscillation of the gauge column, coupled with probable errors of observation due to the attempt to estimate an average reading, would certainly cast doubt on the wisdom of relying on the results within several percent.

Further light could be thrown on this work by the calculation of the probable error of the result as deduced from the variations of individual readings. The writer does not think that the slight variation of the coefficient from unity is of any significance, nor does he believe it can be safely concluded from these tests that the tube reads either slightly too high or slightly

too low; in fact, he is rather surprised at the fairly good agreement of the Pitot tube results with the current meter measurements, in view of the adverse conditions.

The above criticism is made along the lines of Mr. Groat's own statements; and is not intended to reflect on his methods in the least. The current meter measurements at Massena were made with the greatest care and rank with the best work which has ever been done in this department.

Regarding the subject of standing waves, which Mr. Groat introduces, I am in full agreement with Mr. Groat's conclusion that the Merriman formula is defective in principle; but I can see no error in Unwin's method or formula.* The writer hopes to be able to secure experimental data on this subject in the future, however, and will not consider it further at present.

A brief discussion recently submitted by Mr. J. N. Chester calls attention to the fact that it is necessary when using the Pitot tube in large penstocks to install a number of bars and braces to support the tube. This supporting frame is so designed as to offer little resistance to the flow, and it presents an area normal to the flow which is small compared to the area of the penstock. The Pitot tube projects upstream from the frame; and it is well known that disturbances in a stream do not extend far in a direction opposite to the current. In very large penstocks, the frame consists of two perpendicular bars upon which the tubes run, with the addition of lateral stays which brace these bars at points between the ends and center. If the frame affected the Pitot tube reading at all, this effect should be noticeable in local disturbances of the reading in the neighborhood of the lateral stay bars. No such effect has ever been detected, nor has the frame been found to have any influence on the measurement as a whole when the discharge is checked by a weir.

A supplement to Mr. White's discussion has just been received which gives the results of some interesting tests on the static pressures in large open jets. The piezometer used by Mr. White indicates pressures so near to that of the atmosphere that the variations, when compared with the total velocity head in the jet, are insignificant. The writer is inclined to think that

*The Unwin formula is correctly stated by Mr. Groat, but as printed in the 1908 edition of the Encyclopedia Brittanica a typographical error appears.

the small variations noted are due to a tendency of the piezometer to register a slight positive velocity effect; but whatever the cause of the variations, the main points advanced by Mr. White are well established. The gauge-glass readings in this experiment, it may be noted, are subject to a small correction for capillarity. This correction, if it has not already been applied, will reduce the recorded static head by 0.074 inch, as roughly figured.

Mr. Bacharach mentions the ease with which Pitot tubes can be constructed and applied, and reliable results obtained. In this connection it may be pointed out that most of the questions under discussion relate to refinements in the use of the tube involving possible errors of one or two percent. For many engineering applications such errors are not worth discussing and it is a strong argument in favor of the Pitot tube that almost any sort of tube installed in the manner described by the writer, namely in conjunction with a static piezometer-opening in the channel wall, will give results correct within two or at most three percent; and if a coefficient such as is indicated by the methods of the paper—values between 0.975 and 0.98 having been mentioned as applying to average conditions—then the user of this method will be unlikely to go wrong, and can rely on his results being well within one percent of the truth.

When the Pitot tube is applied with care the method is capable of giving results correct within a small fraction of a percent. The I. P. Morris Company has been using the methods outlined above in the testing of turbines for many years and there have been repeated opportunities of comparing the results of different tests. In one case for instance, eleven different measurements of the water quantity discharged by a turbine at a given gate-opening were made, using different sets of observers, the tests being made on different days; the maximum variation of any one result from the average being between a quarter and a half of one percent. Even this small variation cannot be wholly attributed to the water measurement since it might much more probably be caused by variations in setting the turbine gates. Many experiences of this kind have inspired a good deal of confidence in the method used.

MR. BENJAMIN F. GROAT:* Professor Moody presents a most able paper describing a very complete series of experiments upon Pitot tubes. The experiments in which the tube was turned at an angle with the motion are of even greater importance than the usual ratings. Such tests give a very clear idea of what is to be expected of a tube when observed in turbulent water, the effects of which do not seem to have been thoroughly investigated heretofore. The rise of the curve, for this case, above the curve of resolved components points to a coefficient less than unity for flat faced tubes in perturbed water.

This is in agreement with the writer's experiments at Massena, for the coefficient changed from a value greater than unity in the lower parts of the tail race where the flow was very uniform, to a value less than unity in the upper parts of the race where there was considerable turbulence. In this connection it is of interest to note that the Pitot tube employed was of the same general design as tube "*N*" described in Mr. White's paper which has already been mentioned. The dynamic orifice was simply the end of a ¼-inch gas pipe filed flat upon the end so as to form a plane surface perpendicular to the axis of the pipe. Applying Professor Moody's reasoning and the results of his tests, a tube of this design should give excessive velocities in turbulent water if the coefficient unity is applied.

Professor Moody's suggestion that the *degree of turbulence* may be measured by means of the relative performance of two dissimilar tubes suggests further to the writer that an instrument for measuring turbulence might easily be designed by having two such tubes and a static orifice combined in one instrument. An instrument of this kind would serve for determining average Pitot tube heads and the degree of turbulence at the same time. The proper coefficient to be applied to the average head might be read from a turbulence curve and immediately be applied with the head readings to determine velocities. Evidently tubes "*B*" and "*C*" would serve this purpose well.

Professor Moody's theory of the Pitot tube is substantially the same as that of the writer, the main difference being one of algebra rather than of principle. Both theories are identical with the theory of the frictionless fluid presented in treatises on

*Authors Closure.

hydrodynamics where the variation of pressure along a stream-line is investigated, thus giving proof of Bernoulli's theorem. This theorem, though accepted in the case of water flowing through a pipe, seems to have been rejected by a number of writers in the case of the Pitot tube. It was that latter fact which caused the writer to insert the word "fallacies" in the title of his paper.

The investigations of the effects of turbulence upon the various forms of velocity meters which have been conducted by Professor Moody are, indeed, timely. The demands for a higher degree of accuracy in turbine testing and the increasing value of the *bonus* and *liquidated damages* clauses in turbine contracts, render it imperative that hydraulic engineers standardize their methods of testing. Hitherto these methods in America have been very unsatisfactory, to say the least. It is not too much to say that many of the tests which have been executed in this country must be regarded as untrustworthy owing to the fact that still water ratings have been applied to the instrumental readings without correcting for the effects of turbulence, which must have been in evidence in all cases to a greater or less extent. Success in any particular case must have depended upon the particular engineer more than upon the method. It may be a gratification to turbine makers in general to know that their products have, in many cases, been better than the tests indicated.

Pertinent to the remarks of Professor Moody concerning the current meter which he illustrates in Fig. 27, it should be observed that the writer's rule of performance for screw meters, as given in his paper upon current meters, should be applied only to meters answering to his definition of a screw meter. This rule and its limitation follow:

"When a screw meter is run in perturbed water it will register a smaller number of revolutions per second than a perfect still-water rating would indicate."

"A screw is a rotating element, the surface of which would be generated by a straight line perpendicular to, rotating uniformly about, and moving uniformly along, the axis of rotation." "One would also hesitate to apply the propositions to meters having large or badly designed frames which would be likely to interfere with the action of the water on the runner."

We have had many investigations of various forms of nozzle but the method of Professor Moody is the first one published to furnish a positive test for the selection of shapes; it is not necessarily the tube whose coefficient is nearest to unity but the tube which comes nearest to resolving velocities, that we want.

Mr. Grover's broad liberal discussion is esteemed most highly by the writer. It has a breadth of view and a definiteness of purpose which are not to be mistaken. Moreover, it gives an insight into the history and vicissitudes of the current meter in the United States which is interesting, instructive and of the greatest importance to the engineering profession in general.

Mr. Grover writes upon the relation of the Pitot tube to the practical problems of the hydraulic engineer in the measurement of river discharge rather than to the details, or even the merits of the papers themselves. This is very much in line with the writer's own purpose in presenting one of the papers referred to. The object was not to go into great detail or to claim merit for the paper, but rather to open questions of general theory and practice in the hope that some of them, at least, might be finally settled through the medium of the ensuing discussion. That this discussion will be attended with such results is confidently expected. So much theoretical and experimental investigation of the highest order has been consummated in the science of hydrodynamics that it is difficult to comprehend why there are still different conceptions of the theory of the Pitot tube among hydraulic engineers of the highest standing and attainments.

While Mr. Grover has very considerately overlooked the weak points of the paper, many of which must be apparent to most scientific readers, there are one or two which it may be well to examine more critically. He refers to the facts that the large Price meter was employed at Massena and that this type of meter was discarded several years ago by the Survey because of lack of reliability. These two facts in conjunction, without further explanation, would tend to cast a doubt upon the wisdom displayed when adopting this instrument for use in the turbine tests. It may therefore be stated that the large Price meter was chosen as one of the instruments to be investigated and used at Massena because it had been employed in similar tests in the

same tail races several years earlier, and it was desired to have means of comparing the two sets of tests. Instead of finding this instrument to be unreliable, however, it was found to be extremely consistent in its records when it was rated in the tail races at the points where operated. When employed in this manner it will give results agreeing among themselves and with the corrected results of other instruments to a small fraction of a single percent.

The statements immediately above are not to be taken as a contradiction of Mr. Grover's statements relative to the unreliability of the Price meter. He undoubtedly meant that the meter was unreliable when the records were reduced to velocities by means of the still-water ratings of the instrument without any further correction. When it was stated above that the meter is extremely reliable when it is rated in the tail races it was pre-supposed that the comparisons are of *aggregate* velocities, as explained in the paper, rather than of *individual* velocities at single meter points. It is a well known characteristic of the large Price meter that it will over-register relatively to the still water rating when operated in perturbed water. It is not so well known that the meter has a perfectly definite rating in perturbed water, flowing according to an established regimen. The main difficulty, then, with the large Price meter, is not as to its reliability but as to how to obtain its rating in the *steady flow of perturbed water*, if such an expression be understood and be permissible.

As to the Pitot tube, Mr. Grover seems to entertain the opinion that it is much better adapted to the requirements of special investigations than to those of the Survey. This, possibly, is an eminently correct view of the situation, but it may not be amiss to suggest that the Pitot tube can be made in very portable form for use at turbulent stations as a means for determining the deviations of current meters from their still-water ratings. With the manipulation of such an instrument well in hand it would be possible for a good observer to examine the ratings of many of the discarded meters at important stations where it is desirable to revise the past records for the purpose, if possible, of improving the estimates of water supply. Owing to the great facility with which the current meter may be em-

ployed it looks to the writer as though it would not be supplanted by the Pitot tube in its present form, as an instrument for gauging streams, but that the Pitot tube, if given a fair trial, would become a reliable instrument for checking the records of the current meter, especially at turbulent stations. But this is a matter to be settled by those in charge of stream gauging and the engineers of the Survey are amply capable of disposing of the question to the satisfaction of all.

The persistent efforts of Messrs. W. & L. E. Gurley to produce a screw meter have been known to the writer for some time. Indeed he was very cordially received at the manufactory of these gentlemen about two years ago at which time a number of the trial instruments were shown to him and the nature of many of the experiments explained. It is a very creditable undertaking and the writer was impressed with the belief that this firm will not put any instrument on the market until it has been proved to be reliable.

A word upon the design of screw meters may be of interest and value.

Design of Meters: The principal desideratum of a current meter is that it should give the resolved component of velocity in a direction fixed relatively to the meter. The fact that a cup over-registers in turbulent water while a screw under-registers, gives a basis of design which may be used to produce a meter possessing this characteristic more or less rigidly. If the blades of a screw are "cupped" to the proper extent, and in the right sense, the effect may thus be toward neutralizing the retardation which the screw would otherwise suffer.

There are other ways of producing such a meter. Professors Greene and Moody, of Rensseleaer Polytechnic Institute, have conducted a series of experiments there which resulted in the production of a meter practically giving only the resolved components of velocity.

A conclusion to be drawn from these experiences is that a tail, or rudder, is a useless appendage to a meter used in stream gauging. The meter should be held rigidly in the stream or conduit, giving only the component of velocity perpendicular to the cross-section. A cup meter would give better results in turbulent water if it had no tail, but was simply allowed to run

at the end of a vertical rod like an inverted cup anemometer.

The recording device for a meter designed to be held rigidly in the current should register positively for down-stream current and negatively for up-stream current. There are cases where the current beneath the surface is up-stream; and the old forms of meter make no distinction, as they should.

There are many other requirements which might be mentioned. Perhaps the protection of the rotating element from floating debris is the most important. This element should never be surrounded by a frame of any kind and should be so shaped that it will not gather any floating material, weeds, grass, etc. The shape of runner adopted by Dean Haskell in the design of his current meter has proved itself extremely efficient in shedding all floating matter. Even with a proper shape of runner the meter will become clogged if the runner is surrounded with a sheath of any kind, either attached to the runner or the frame. Dean Haskell has also taken care of this point, for his runner projects beyond all other parts of the instrument. It remains then only to give the blades of the runner a slight concavity on the side upon which the water impinges, to remove the tail and connect the meter rigidly with the rod, or support, in order to have a meter which will give the resolved component of the velocity, and, therefore, one which will give correct indications of velocity in a given direction in turbulent water. The Haskell meter in its present form is not greatly affected in moderately perturbed water, so the change in shape of the blades would probably be quite small in amount.

The question of friction in a current meter is very interesting. Throwing out the case of low velocities, the necessity seems to be, not so much for a small amount of friction as for constancy of amount. If the resisting torque is large but constant, a rating should be fixed just as exactly as in the case where the friction is small and constant. Notice, too, that there is a resisting torque caused by the hydraulic skin friction on a screw, which can be made as large as desired by lengthening the vanes along the axis. In this respect, the screw is just as much a differential meter as is the cup meter.

The retarding skin friction has a much longer lever arm than the bearing friction, and has a much larger resisting torque.

so that the bearing friction of a screw meter offers a resistance of secondary importance. Further, the resisting skin friction is a fixed function of the velocity, varying approximately as the square thereof. Hence it is clear that the principal portion of the resisting torque is fixed for each velocity and cannot be changed. It follows that, if the meter is kept in only fair condition, the rating is not affected seriously by moderate changes in bearing friction. The truth of this was tested in the experiments at Massena by taking part of a rating while the bearing was dirty and stiff, then completing the rating after the meter had been cleaned and oiled. There was no appreciable difference in the two parts of the rating. The Haskell meter is not therefore sensitive to moderate changes of bearing friction.

The screw meter has one other advantage which has not yet been mentioned: The screw, or propeller, may be made exceedingly light, so that the effects of inertia are reduced to a minimum. It is quite possible that the inertia of a heavy revolving part, in conjunction with the reaction of the water, may play an important role in changing the rating when the velocities become variable.

As to the work of the Survey, as outlined by Mr. Grover, there is little to criticize. The cup meter, be it the large or the small type, is sufficiently accurate under favorable conditions for stream gauging when rated in still water without further correction. If any errors have been committed they will most likely be found in the steep turbulent streams of rough country and, even in that case, the current meter observations need not be lost, for, by means of the Pitot tube or the chemical method of measuring the discharge, the errors may be found and corrected. It is one of the important conclusions drawn from the Massena tests that the cup and screw meters both have definite ratings in turbulent water. No error will probably result if this is extended to include every instrument which can be rated in still water, whatever the type or the mechanical principle upon which it operates. This fact ought to be of the greatest value to those engaged in measuring the discharge of streams as well as to those engaged upon other classes of discharge measurements, for it renders available at once the results of all former gaugings which may have been discarded owing to the

apparent, but not real, unreliability of the current meters employed. The still-water ratings simply did not apply. When their turbulent-water ratings are determined for each station by suitable means, the discarded gaugings become available and they will be found to be as reliable as any.

Mr. Grover's suggestion that the requirements of turbine testing are different from those of stream gauging is, indeed, very appropriate. While the general importance of stream gauging is undoubtedly very much greater than that of turbine testing, the money value of a particular turbine test, on the other hand, may run into many thousands of dollars more than that of a particular stream gauging. Special efforts, special methods and special instruments are, therefore, demanded. The required degree of precision is rather for hundredths of a percent than for a single percent. The hydraulic engineer first turns to the instruments and methods employed in stream gauging. He finds them unsuited to his requirements and tries the Pitot tube. This proves more satisfactory as regards accuracy but it is still unequal to the niceties demanded. Chemistry is the next resource and, as outlined in the Appendix to the writer's paper, it promises to give still better results. The theory of the latter method is certainly more satisfactory than any yet proposed for the measurement of flowing water in large volume.

It is very clear that any government should study the general character of its water-sheds. In order to do this it must make appropriations for the study and these appropriations should be sufficient for the purpose. The great difficulty in determining public appropriations is always identical with that in determining the limit to public service. Just where does public service end? In view of the immensity of our country and the apparently enormous sums which have been appropriated for other branches of the public service, it does not look as though the funds appropriated for gauging streams have been any too large. The writer is, therefore, of the opinion that these appropriations might well be increased for a few years at least. The financing of public projects, however, leads to economic and social questions of the deepest kind. Society is an organized aggregate possessed of mutually acting and re-

acting elements. Up to the present it seems to have defied all attempts at scientific treatment. The usual procedure is to set in motion a social action, if such a term be acceptable, and then let the reaction take care of itself. We are undergoing such a process of readjustment in our financial and business systems at the present moment and no one feels competent to prophesy what the final result will be. We must await the "end reaction" as the chemist would say.

Next in importance to the conservation of human energy is the conservation of natural resources, and among the most vitally important of the natural resources are our food and water supplies. It is therefore imperative that liberal appropriations for the development of the latter be made whether it be from public or private funds. But let it be understood that conservation must mean development of resources and not a dispute over the possession of property.

Mr. Roberts is undoubtedly very correct when he states that the engineers on river work who have had "experience with gas and water supplies for communities and mills, have definite knowledge of the value of pitometers in measuring the discharge through pipes and other confined areas where current meters could not possibly be employed. However, these same engineers would not in their river work use tubes." It would seem to the writer that this omission to employ the Pitot tube in river work is not so much because engineers consider the tube unfit for such work as because they look for generally accepted methods and the precedents for these uses of the tube are few.

The writer has expressed the opinion elsewhere that the Pitot tube is not likely to supersede the current meter for stream gauging on account of the great facility with which the current meter may be handled and observed. It would probably add greatly to the accuracy of stream gaugings, however, if the meters were rated by means of the Pitot tube in the cross-sections of the gauging stations. Such ratings, particularly at turbulent stations, would enable the observers to correct the meters from time to time and for different stages of water. The experience of the writer is that these corrections would be practically constant for the same stage at a given station. When,

therefore, it is discovered that a series of gaugings at some station has been seriously affected by turbulence for a number of years, it would still be possible to correct the original discharge curve by a few comparative ratings with a Pitot tube at different stages. A rating of this sort is as exact and as accurate as a still-water rating, while the still-water rating will not serve on the turbulent station.

In the discussion with Mr. Grover the writer has presented his views upon the design of current meters intended for use in turbulent water, negative currents, etc. He has expressed the opinion that a current meter should give the resolved component of velocity in a direction fixed relatively to the meter; that there should be no tail or rudder; and that the instrument be held rigidly in the cross-section of the gauging station. The recording device should distinguish between positive and negative velocity. This kind of instrument, when provided with the cupped vanes also described, would be practically correct even in very bad cases of cross-currents and reversed currents.

Mr. Roberts gives an interesting description of the attempts to gauge the low water discharge of the Monongahela River. Not the least of the difficulties was the extremely low velocities which the observers had to measure and this was combined with an unusual tangle of cross-currents. Is this not a condition which the chemical method meets most perfectly? The main difficulty would be to secure a uniform mixture throughout such a broad sluggish current. Under these circumstances the writer suggests the use of several scows anchored systematically across the channel at a suitable distance above the section where the samples are to be taken; each scow to be provided with its tank of chemical and an efficient centrifugal pump taking water from the river above the boat and discharging it back again below the boat vertically downward after being dosed with the chemical. These pumps, properly placed and operated, would, in large measure, aid in securing a satisfactory mixture.

Mr. Knowles gives a most interesting account of an early series of experiments by himself and the late Mr. Louis Francisco, Verges, S. B. These experiments show that the coef-

ficient of the Pitot tube is almost exactly unity when the formula is $v^2 = 2gh$. Further, the distribution of velocity in a jet of water was most thoroughly investigated in three dimensions in the region of the "vena contracta" and the plane of the orifice. It is interesting to note the close agreement among all the investigators as to this distribution, including the distribution as found by Beresford as early as 1878. The experiments are also of more than usual interest on account of the high head upon the orifice.

Mr. Knowles' cogent remarks upon the application of Bernoulli's theorem are both timely and to the point. It is clear to the writer that there are cases, such as that of the free vortex, where the energy-head of each particle is equal to that of any other particle whether these particles flow in the same or different stream-lines. But there is nothing in the mechanics of liquids, real or ideal, which requires this to be so. In the case of the forced vortex, for example, the dynamic head and velocity-head increase, or decrease, together, by equal amounts. If Bernoulli's theorem were applicable, generally, to this case the dynamic head should increase exactly by the amount that the velocity-head decreases and vice versa. In short, there are cases where Bernoulli's theorem applies to all the particles in the same stream-line but not generally to particles in different stream-lines.

We are honored with a discussion by Clemens Herschel, inventor of the Venturi meter and the fall increaser and designer of a current meter. The invention of the Venturi meter must be classed as one of the great triumphs of the human mind. Mr. Herschel grasped the idea and immediately produced an instrument which is destined to serve man for many years to come. The value of such an instrument to mankind cannot be measured in money units. In fact, the metering of water from natural water supplies is, perhaps, one of the most important operations connected with conservation. When, therefore, so deep an hydraulist as Mr. Herschel in the present discussion, and in his adverse criticism of a paper by Charles H. Tutton,* compares particles of flowing water to the "contents of a feather

*A Proposed Solution of Some Hydraulic Problems, *Transactions*, Am. Soc. C. E., vol. 47, p. 372 (1902).

bed turbulently floating down the street in a gale of wind'' the comparison, though somewhat humorous, should receive the respectful attention of those interested in the subject.

It is certainly known by all that, in most actual cases of water flowing in streams and pipes, the ideal *stream lines* of *steady motion* do not exist, but on the contrary a condition of turbulence prevails. Mr. Herschel concludes from this that velocity-curves have no place in engineering, and that much time has been wasted by experimenters in studying them. He also describes an interesting experiment by George H. Benzenberg† wherein the volume of discharge of a sewer 12 ft. in diameter and 2534 ft. long was determined. Two ounces of red eosine dissolved in a quart of water, were suddenly injected into the sewer at one end while the discharge of this colored water half a mile farther down was observed. The discharge was accurately determined because ''the color was readily perceptible at the outlet and was never distributed over a length of more than 7 to 9 ft., being about one-third of one percent of the length of the tunnel, the center of which was taken at the point observed. The compactness of the coloring matter showed that the velocity was practically uniform at all points in the cross-section of the tunnel, which again in itself was very uniform throughout the entire length of the tunnel.''

Mr. Herschel then seems to conclude that the flow of water is governed by ''the uniform averages of a multitude of chance effects'' rather than by any ''action of the physical law of flowing water.'' But what is a chance effect? It can be nothing else than something which cannot be anticipated or explained. It does not follow, however, that there is no law governing chance occurrences. On the contrary every occurrence must take place in full accord with physical law. Hence the expression ''uniform averages of chance effects'' as applied to flowing water can mean only that the laws of flow are unknown. If we examine the kinetic theory of gases we shall soon convince ourselves that some of the most important laws of physics

†Sewerage System of Milwaukee and the Milwaukee River Flushing Works, *Transactions* Am. Soc. C. E., December, 1893.

can be derived by an application of the principles of the calculus of probability.*

While the writer is inclined to agree with Mr. Herschel that much time has been wasted in the study of velocity-curves for the purpose of generalizing the laws of flowing water, he is unable to conclude, either from the existence of turbulence or from the results of the color test, that there is no such thing as a velocity-curve. If by velocity we mean the average velocity at a point in the cross-section of a pipe or channel it is amply proved that, for a fixed regimen, this average is practically constant if the time observation be sufficiently extended. The plotting of a series of such velocities taken transversely across the section of a pipe or open channel, will give a perfectly definite velocity-curve; and such curves are of great service in computing the discharge from point observations by current meters and Pitot tubes. The distribution of such average velocities in a tail race becomes perfectly fixed for given conditions, so that, when the distribution is once determined, the discharge may be computed accurately from a single point observation under the given conditions.

Nor is it clear to the writer that the "filaments of the school books" must be discarded because in turbulent flow there are no filaments. If we were to act generally upon this lead we should be unable to reason upon any subject. For reasoning is based upon assumptions to begin with and it is well understood that nearly all classes of assumptions are imperfect. The necessary requisite of an assumption is, that it express the principal facts with sufficient exactness to lead to an approximately correct conclusion, even though the majority of the operative causes be neglected. Thus, the assumption of a frictionless fluid leads to a very accurate formula for the velocity of discharge at the center of a jet issuing from an orifice in a vessel of thin walls, because viscosity and skin friction, in this case, have only minute effects. It should be observed that the general definition of a stream line does not require that such lines be traversed by a particle of water.

*The Kinetic Theory of Gases, by Oskar Emil Meyer, translated by Robert E. Baynes. Longmans Green and Co., London and New York. (See the Mathematical Appendices).

The writer believes with Mr. Herschel that the Venturi meter should have been used in the past more frequently than it has been, but does not attribute this "human inertia" to any "ill effects of mis-information acquired during the days of schooling." Our schooling is bad enough, but men who rise to be real engineers are sufficiently wise to glean the better part of their education and training. At the same time it is a fact that engineers have continually to combat human inertia. Frequently they are compelled to expend much more energy in convincing their clients and employers of the propriety of a project than is afterward required to put it through. It is plain, under these circumstances, that the human acceleration acquired depends entirely upon the relative magnitudes of the impressed human force and the resisting human inertia.

[Additional discussion of these papers, if received, will be published in a later issue of the Proceedings.—Editor.]

"HOW THE ANCIENTS WOULD HAVE CONTROLLED THE MISSISSIPPI AND ITS TRIBUTARIES"

By Sir William Willcocks*

[This paper was published in the March, 1914, issue of the Proceedings of the Society. Discussions of the paper appear in April, 1914, issue. Additional discussion if received will be published in a later issue.]

DISCUSSION

Mr. C. McD. Townsend:† No matter how eminent a man may be, if he is unfamiliar with the laws and customs of a people, he is liable to make serious mistakes if he enters into ther controversies.

In his paper on "How the Ancients would have Controlled the Mississippi and its Tributaries", read before the Engineers' Society of Western Pennsylvania, Sir William Willcocks has revived discussions which agitated the Mississippi Valley fifty years ago, and with a necessarily superficial knowledge of his subject, has added the prestige of a great name to hydraulic heresies which have been refuted often.

It is possible that the Ancients would have built cut-offs if they had been in charge of the Mississippi river. They knew little about the depth in their rivers, and cared less. Their navigation of inland waterways was confined to vessels comparable to the birch bark canoe of the Indian, or the bateaux of the early voyageurs. The barge on which Cleopatra seduced Anthony and changed the destiny of the world was only a good-sized row-boat, and as late as 1814 Commodore Perry, when he decided the question of British supremacy in our Northwest Territory, sailed from Erie, a port having but six feet of water on its bar, and brought his captured vessels in a

*Consulting Engineer, Cairo, Egypt.

†Colonel, Corps of Engineers, U. S. A.; President, Mississippi River Commission, St. Louis, Mo.

sinking condition into Sandusky Bay, where there was a navigable depth of but nine feet. In fact, it was not until the utilization of steam in the navigation of our rivers in the forty's that there was any particular necessity of paying much attention to their depths.

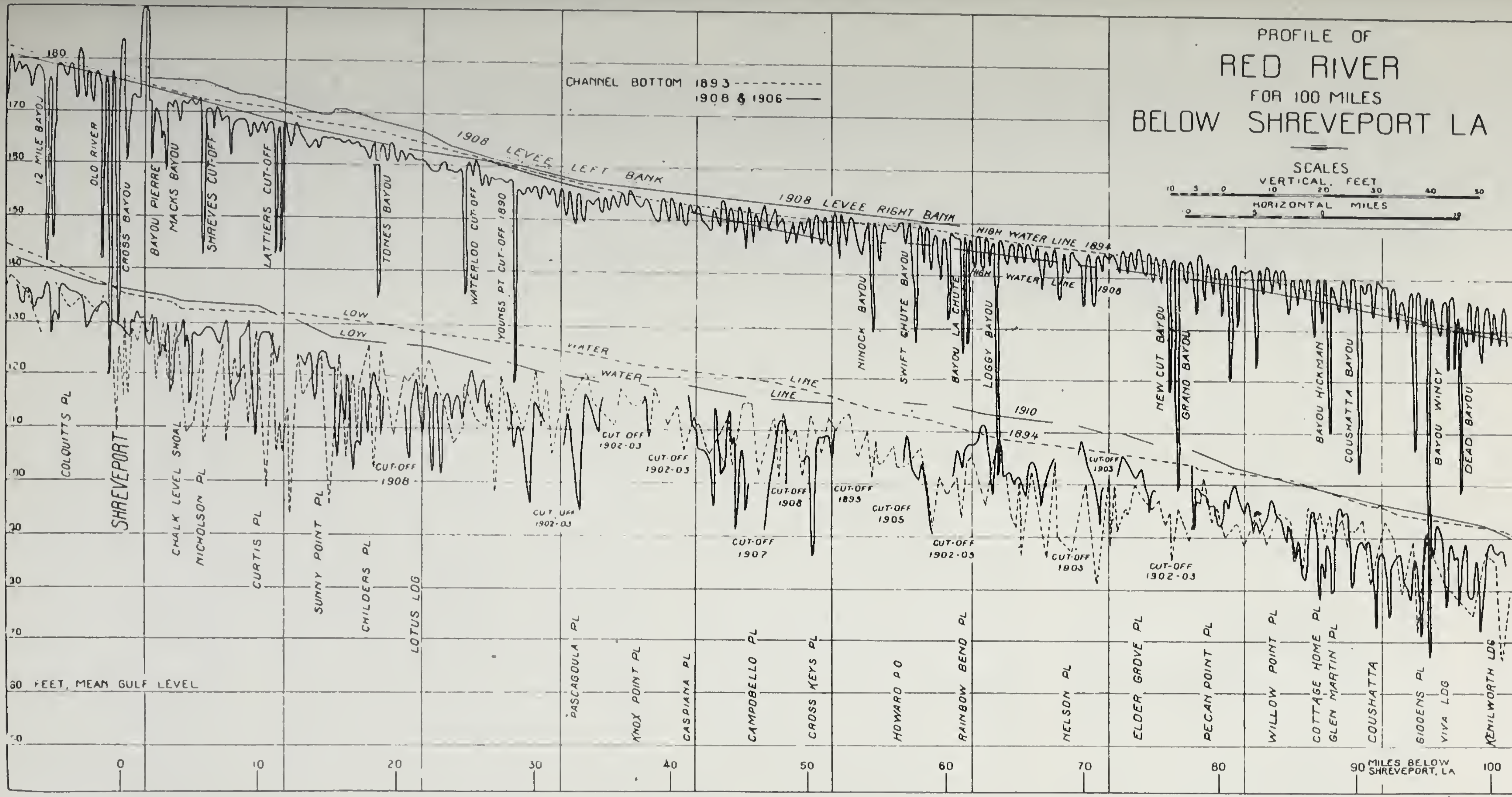
The science of river hydraulics has been almost entirely developed from investigations undertaken within the past century. The knowledge of the Ancients of the principles of hydraulics of any kind was most scanty,—their knowledge of river hydraulics almost nil. They even attributed the rise and fall of rivers not to natural causes, but to the wrath of the gods.

To urge the works of the Pharaohs and Nebuchadnezzer, of Noah and Joseph, as reasons for disregarding the teachings of Debauve and De Mas, of Fargue and Girardin, of Schlicting, Hagen, Jasmund, Engel, and Liliavski, reads more like a page from Mark Twain than an extract from a serious engineering discussion.

If the Ancients had made the cut-offs proposed by the illustrious author, and the river had remained shortened as designed, they would have utterly ruined its natural low-water navigation by anything but flat boats. To reduce the length of a river 40 percent would increase its mean slope a corresponding amount. The depth on crossings is an inverse function of the slope. As the river in its present state tends, without improvement, to low-water depths of about 4½ feet on its crossings, it is readily seen that such a radical change in its regimen would reduce its natural navigability to about that of the Missouri above Kansas City.

Both De Mas and Girardin call especial attention to the injurious effects of cut-offs and an excessive straightening of a channel, on navigation, citing examples in European rivers. Their remarks are fully confirmed by experience in the United States. The Kaskaskia cut-off on the middle Mississippi, which occurred in 1880, reduced the slope and caused excellent navigation through the cut-off, but at the expense of increased slopes and annual dredging above and below it, producing almost identical results with those described by M. Girardin in the Canal de Miribel on the Rhone.

The Red River, however, affords a still more striking ex-



PROFILE OF
RED RIVER
FOR 100 MILES
BELOW SHREVEPORT LA
SCALES
VERTICAL, FEET
HORIZONTAL MILES
CHANNEL BOTTOM 1893
1908 & 1906
1908 LEVEE LEFT BANK
1908 LEVEE RIGHT BANK
HIGH WATER LINE 1894
HIGH WATER LINE 1908
LOW WATER LINE
1910
1894
FEET, MEAN GULF LEVEL
MILES BELOW SHREVEPORT, LA
12 MILE BAYOU
OLD RIVER
CROSS BAYOU
BAYOU PIERRE
MACKS BAYOU
SHREVES CUT-OFF
LATTIERS CUT-OFF
TONES BAYOU
WATERLOO CUT-OFF
YOUNGS PT CUT-OFF 1890
NINOCK BAYOU
SWIFT CHUTE BAYOU
BAYOU LA CHUTE
LOGGY BAYOU
NEW CUT BAYOU
GRAND BAYOU
BAYOU HICKMAN
COUSHATTA BAYOU
BAYOU WINCY
DEAD BAYOU
COLQUITTS PL
SHREVEPORT
CHALK LEVEL SHOAL
NICHOLSON PL
CURTIS PL
SUNNY POINT PL
CHILDERS PL
LOTUS LDG
PASCAGOULA PL
KNOX POINT PL
CASPIANA PL
CAMPOBELLO PL
CROSS KEYS PL
HOWARD P O
RAINBOW BEND PL
NELSON PL
ELDER GROVE PL
PECAN POINT PL
WILLOW POINT PL
COTTAGE HOME PL
GLEN MARTIN PL
COUSHATTA
GIDDENS PL
VIVA LDG
KENILWORTH LDG
CUT-OFF 1908
CUT OFF 1902-03
CUT-OFF 1907
CUT-OFF 1893
CUT-OFF 1905
CUT-OFF 1903

ample of what may be expected from permitting a river to develop along the lines recommended by the distinguished author.

The Red River was originally obstructed by snags and floating debris which lodged upon them, which seriously diminished the flow of water in the main channel. The removal of the rafts, as such obstructions were locally called, largely increased the discharge, and the river in its efforts to adjust itself to the changed conditions made numerous cut-offs, aided in some cases by the planters along its banks. The river between Shrevepost and Alexandria, originally 218 miles in length, was shortened about 26 miles. The results for 100 miles below Shreveport are shown on the accompanying profile. The marked rising of the river bed in the lower portion of this stretch is to be particularly noted.

The criticism of the Mississippi River Commission for increasing current velocities by levees, while showing extraordinary nervousness about increasing them by cut-offs, loses its force when it is recognized that a levee increases velocities only during floods, when they can do little damage to the low-water channel. As soon as a river recedes below a bank-full stage, the influence of a levee is nil; a cut-off increases velocities during extreme low-water, when they have the most injurious effect on navigation.

There is another peculiarity of rivers that the illustrious author has failed to consider. Unless the Mississippi River be held as in a vise, it is impracticable to permanently diminish its length. When a cut-off occurs there is at first a violent change of slope in the immediate vicinity, accompanied by an increase of velocity in the river channel, which largely increases the caving above and below. By this means the river strives to regain the length it has lost. One whose personal knowledge of the river has been confined to a day's visit at Memphis, might readily make the mistake of assuming that the effect of a cut-off was confined to a single season, but one who has studied the neighboring river gauges finds that its effect extends over a period of some twenty years, in fact, until the river by means of the caving of its banks has acquired the length it had before the cut-off was made. The Centennial cut-off at Vicksburg

(1876), did not produce its maximum effect on the Lake Providence gauge, 55 miles above, till 1895. Notwithstanding the numerous cut-offs that have occurred since the discovery of the river, its length today does not differ materially from what it had two hundred years ago.

If the Ancients had made cut-offs, they would have enormously increased the rate of caving of the river, would have destroyed a large amount of very fertile land, and after 30 or 40 years would have had nothing to show for the labor, as the river in that period of time would have acquired its original length.

Mr. Oppikofer calls attention to the tendency of rivers when flowing in a valley formed of their own alluvium, to assume cycloidal curves. The formation of a cut-off temporarily destroys this curve, and the river strives to regain it. Prof. Engel, in his work on river improvement, discusses the difficulty of permanently improving a river when in a state of transition.

While the distinguished author ignores the subject of the navigation of the river, which is the one the Commission has by law first to consider, even as a method of flood prevention, his project is extremely faulty. He recognizes that the method of cut-offs on the river Theiss led to most disastrous results, but believes that it was due to an unscientific handling of the subject, claiming that cut-offs should be made not from the head of the river down, but from the mouth of the river up. He appears to ignore the fact that bends susceptible of being cut off are not uniformly distributed along the Mississippi River, that below New Orleans there are none that could be so treated, and but few below the mouth of Red River, while in the middle reaches they are numerous. To start at the lower end of the river and make such cut-offs as are practicable would soon invite at New Orleans a similar tragedy to that which occurred at Szegedin on the Theiss. Nor is it safe to permit the river to work out its own salvation as he suggests. In the bends above Greenville one cut-off would most certainly produce several others, and create such a shortening of the river, at least temporarily, as would seriously increase flood heights from Greenville to Vicksburg where they are now abnormally high.

Humphreys & Abbot, in their work on the hydraulics of

the Mississippi River, estimate that the effect of a cut-off is to raise the water level just below it an amount equal to one-half the fall of the river in a straight portion equal in length to the shortening of the channel.

The illustrious author repeats a mistake that was made by several prominent American writers some 30 years ago. He recognizes that a river attempts to adjust its area of cross-section to its discharge, and therefore concludes that if a single basin is leveed, and we wait till a great flood comes down the river, it will scour out a channel which will permit the flood to pass with but a slight increase in flood heights, but he is a little more confident than his American predecessors and specifies one foot as the increase in flood heights to be permitted.

He ignores, however, two important considerations, that in all work, time is a most important factor, and that while a river strives to enlarge the area of its cross section to permit a large discharge, it is equally as strenuous in its efforts to diminish its section when the discharge is small. This is particularly true in a river carrying a large amount of sediment that is readily deposited or scoured.

A discharge of 2 000 000 second feet occurs in the Mississippi Valley possibly once in 20 years, and then lasts but a few days. It has power to destroy, but not time to create an adequate channel a thousand miles long, or even in front of one of the basins. Extreme low water conditions are equally infrequent, but the river is above a mean stage through periods of time in which it is capable of performing adequate work.

His premise should therefore be modified to read that a river is always striving to adjust its cross section to its *mean* discharge, and whenever either extreme high or low water conditions occur, the river is not adjusted to them. It would be difficult to determine with mathematical precision the influence of levees on the mean discharge of a river, but observations at Dusseldorf on the Rhine indicate that the levees of that river have enlarged the section sufficiently to reduce flood heights about one foot in one hundred years. If the Mississippi is governed by the same laws as the Rhine, to comply with the requirements of the author, at New Orleans, where the river has already risen over six feet from levee construction, would necessitate

spreading the work of levee construction along the Mississippi River over a period of some 500 years,—a pretty long period even for the despots of Mesopotamia to wait for results.

The United States has played but a secondary part in the construction of levees; two-thirds of the work has been done by the communities affected. If in 1882 the people of Louisiana had been assured by the Commission that there would be no levee construction in the States above, until their levees were in a condition to receive the increased discharge, the cultivation of the remainder of the valley would have been practically abandoned, and the levee line of Louisiana would not have attained the strength that exists today. It is not in human nature to tax oneself for the benefit of one's neighbors, and it has required the spur resulting from the knowledge that flood heights were going to rise, to force Louisiana to keep pace in levee construction with the work that has been done in the upper districts.

The author's assumption that the depth of water over the country was greater during the floods of 1912 and 1913 than in 1882, is incorrect. The water was not only lower, but a considerably smaller portion of the country was flooded. The greater damage resulted from the fact that in 1912 there was more to destroy than in 1882, due to the development of the county in the interim.

A flood of 2 000 000 second feet does not occur on an average once in 20 years. The existing levee line can safely withstand floods on an average of nine years in ten. While it is extremely desirable to complete the levee line as soon as possible, the country will continue to prosper under existing conditions, just as it did from 1880 to 1910, when the levees were much weaker than at present.

The writer, some twenty years ago, in papers presented to the Mississippi River Commission and various Engineering Societies, discussed the influence of the St. Francis Basin on levee heights, and the question of its utilization for reservoir purposes. While predicting the height that floods have since attained, his investigations showed that it would be cheaper to build a levee line the entire length of the river than to construct the dams necessary to retain the flood in the basin. While the project of the author differs from the usual St. Francis Reservoir pro-

jects that are annually submitted to the Commission, in that it does not propose to confine the entire flood discharge, the increase in the value of lands in the past 30 years, that it would be necessary to condemn, would preclude the use of the basin for reservoir purposes.

The author's suggestions as to methods of construction are equally interesting. Biblical references to bricks made with or without straw, does not justify their employment on the Mississippi river in this age of concrete, when the Germans have experimented with bricks on the Rhine and rejected them, because they were washed away.

British writers are better authorities on the construction of harbors and docks than of inland waterways, but if Sir William Willcocks had been familiar with the writings of his own countrymen, he would never have recommended detached revetments for the protection of river bends.

Prof. James Thompson, F.R.S., in 1879, in some remarks before the Institution of Mechanical Engineers at Glasgow, described the motion of river currents in bends, and his deductions have been fully confirmed by the experiments of Liliavaski on the Dneiper River.

In bends the surface currents do not flow in parallel lines but tend to diverge from the convex toward the concave bank, where the water piles up, thus producing an appreciable difference of head on opposite banks. This difference of head increases as the velocity increases. When the velocity is swift and the caving is therefore at a maximum, the great mass of the surface water that impinges on a concave bank does not remain on the surface, but flows down the bank across the river close to its bottom and rises to the surface on the convex side, carrying with it the material it erodes from the bank.

When the upper portion of a bend is revetted, it only affects the filaments which impinge against the portion thus protected. The filaments further out in the stream attack the unprotected bank below, with approximately the same force they would have had if the portion above had not been protected, and deep pockets are scoured out, making sharp salients of the revetted portions. This process is continued until during some flood a cut-off occurs across the salient, and the revetment will

then be found on the convex side of the stream facing the sand bar instead of the channel. This form of revetment under the name of bank heads was tried quite extensively on the Missouri river about 16 years ago, and some of these bank heads are now about three miles from the river channel.

A corrollary to this error is found in the statement that the sediment carried in suspension into the river from its tributaries, is deposited, while the sediment found in its lower portions is derived from its caving banks. Both Messrs. Fargue and Liliavski have demonstrated that the greater part of the material caving into a stream in bends is deposited on the bar opposite and just below the point of caving, forming the sand bar which obstructs low-water navigation. Observations on the Mississippi show that a large portion of the sediment entering the Mississippi river from the Missouri is carried to the Gulf without being deposited, and that water from the Ohio never attains from caving banks the degree of saturation that exists in the Missouri during floods, nor in the Mississippi from floods derived from the Missouri.

A careless reading of Major Dabney's remarks, has led to another error. Major Dabney does not advocate a double line of levees for the Mississippi Valley. The sub-levee he employs is practically an extension of the banquette of the levee proper in front of it. When a levee has a base whose width is about eight times the height of the water against it, little trouble is experienced in ordinary soils, but occasionally the alluvium is deposited on brush heaps or other porous strata, and the soil is permeable for long distances. Under such conditions Major Dabney recommends a sub-levee of a height of an ordinary banquette, connected to the main line, and surrounding the permeable section which is permitted to fill with water to the height of the banquette, and by this means the head on the permeable soil is reduced and the danger of sand boils diminished more cheaply than by enlarging the banquette.

A distinguished French General is quoted as saying that he who hath made no mistakes hath not made war, a saying which is equally applicable to the Engineering profession.

The Mississippi River Commission recognizes it has made many mistakes, but it also claims that it has achieved great

successes. It has created a navigable channel in the river exceeding in depth that of any river in the civilized world, not excepting the Rhine with its 50 000 000 tons of freight, and maintains it at a cost per mile less than one-third that of the average railroad of the United States. With the assistance of local authorities, it has constructed a levee line which successfully protects 20 000 square miles of the alluvial valley from overflow until the river attains a discharge of 1 750 000 second feet, as a result of which, while "in 1880 the Delta had a population of 445 604, in 1910 it had a population of 829 720, or nearly double the number of people. In 1880 there were 1 619 721 acres in cultivation, in 1910, 3 585 070—over double the productive area. Farm land values increased from $50 961 199 in 1880 to $174 187 559 in 1910, or three and one-half times. The value of personal property on these farms in 1880 was $12 776 012, and in 1910, $50 115 939, or four times as much. In 1880 the means of transportation in the Delta was almost entirely by steamboat, for there were then less than 500 miles of railway, while in 1910 there were over 3200 miles of railway. Leaving out Memphis and Vicksburg, which are not in the Delta, in 1880 there was only one banking institution in this vast section—at Helena, Ark.—with a capital of $20 000 and with no published statement of deposits. In 1910 there were 246 banks with a combined capital and surplus of over $15 600 000 and with deposits of over $43 300 000." (A. S. Caldwell, address delivered before the Alumni of the University of the South, Sewanee, Tenn.)

The questions above discussed were decided by the Commission 15 or 20 years ago, after an elaborate presentation of evidence and extensive discussion. On the living issues, which are at present interesting the country—the rise of the river's bed, reservoirs, and outlets—it is extremely gratifying to note that the distinguished author indorses the position taken by the writer in several papers recently published.

In reference to the problems around Pittsburgh, the writer was a member of the Board of Engineer Officers that discussed the bridge problem, and disapproved of the irregular location of piers in the Pittsburgh harbor, because of the danger of boats in a swift current. As long as the area of the river's cross

section is not altered, the re-arrangement of piers in straight lines would make little difference in flood heights, if there is a distance of even the length of a city block between bridges. Piles have been driven around crevasses on the Mississippi river in rows in quincunx order to break the force of the current, but the rows have to be close together or the effect of the irregular spacing of the piles is lost.

The writer was also a member of a Board which considered the question of flood control of the Allegheny and Monongahela rivers. If the author had read its report he would not have considered it necessary to advise American engineers to make borings before building masonry dams.

AIR IN JET CONDENSERS

By C. L. W. Trinks*

About eighteen months ago the statement was made before the Society that a jet condenser was nothing but a vessel in which water and steam were thoroughly mixed. This statement drew the prompt reply that air in the condenser and the capacity of the air pump might have something to do with the performance of the condenser.

The present paper deals mainly with the latter phenomenon, namely, the influence of air on the performance of jet condensers. The investigation was limited to jet condensers; partly, because I have had more experience with that type, but mainly because the effects of air in surface condensers have been quite thoroughly investigated by others. (See for instance Orrok, Proceedings of American Society of Mechanical Engineers 1912, or the very complete paper in London "Engineering", January 1914, by one of the editors.) The purpose of the present paper is not to give a complete theory of the jet condenser. Such a theory cannot be given, because, in contradistinction to the surface condenser the extent and shape of the heat transmitting surface are not known in jet condensers.

However, a little theory will give us limiting conditions and will thereby help us to understand practice better. For this reason the weight of steam which strikes unit area of the walls of the containing vessel in unit time, due to molecular vibration, will be given. From the kinetic theory of gases, it is known that the quantity striking a square foot each second due to molecular vibration is approximately $\sqrt{\frac{3p}{v}}$, where p is the absolute pressure in pounds per square foot, and v is the volume of one pound in cubic feet; (approximately because steam is not a perfect gas). From this formula follow these figures:

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*Professor of Mechanical Engineering, Carnegie Institute of Technology.

Vacuum referred to 30 in.	Pounds striking one square foot per hour.
25 in.	10,000
26 "	8,000
27 "	6,000
28 "	4,000
29 "	2,070
29½ "	1,060

Those who are not familiar with the intricacies of the kinetic theory may check the general correctness of these numbers in the following manner: Steam of 28 in. vacuum is usually allowed to travel at a velocity of 400 to 600 feet per second. The weight passing a square foot per hour is then, roughly,

$$\frac{500 \times 3600}{350} = 5000 \text{ lb.}$$

This substantially agrees with the figure obtained from the molecular vibration. If all the steam striking cold surfaces could be condensed, very small condensers would suffice.

As before stated, condensation coefficients for jet condensers are not well established, but we know that, for surface condensers, one of the best heat transmission coefficients on record is 1400 B.t.u. per square foot, hour and degree Fahrenheit mean temperature difference. Allowing an average temperature difference of 20° F., we find the weight condensed per sq. ft. and hour to be

$$\frac{1400 \times 20}{1000} = 28 \text{ lb.}$$

(where 1000 is roughly the latent heat of steam). This weight is, for 28 in. vacuum, only 2/3 percent of the total steam impinging upon the tubes in the same time. From tests which I have made on jet condensers, I know that the condensation rate in them is considerably higher than in surface condensers, but is still very small compared to the value given by thermodynamic theory.

Two reasons for this discrepancy are:

(1) Air in condensers.

(2) Insufficient heat transmission within the drops or sheets of injection water.

The present paper deals principally with the first, that is

to say with the effects of air, although the effect of heat transmission within the cooling medium will receive some attention.

The effects of air are well illustrated by the results of a demonstration test on an experimental jet condenser, which was erected at the Carnegie Institute of Technology especially for

Fig. 1. Arrangement of Testing Apparatus.

collecting data for the present paper. The test arrangement is shown in Fig. 1. The tail water was discharged through a 35 foot barometer tube into the room below. Steam was throttled from boiler pressure and enough water was sprinkled on the steam pipe to make the steam dry saturated or slightly moist when entering the condenser (at condenser pressure).

In the particular test under consideration, a constant rate

of water flow and a constant rate of steam flow were maintained. The speed of a reciprocating air pump which took air out of the cool top of the cendenser was also maintained constant. A variable quantity of air was admitted with the steam through orifices. Although the weight of air admitted through the largest nozzle did not exceed 1.4 percent of the weight of steam entering in the same time, the vacuum dropped from 28½ in. to 23.2 in., which means the difference between very good vacuum and very poor vacuum.

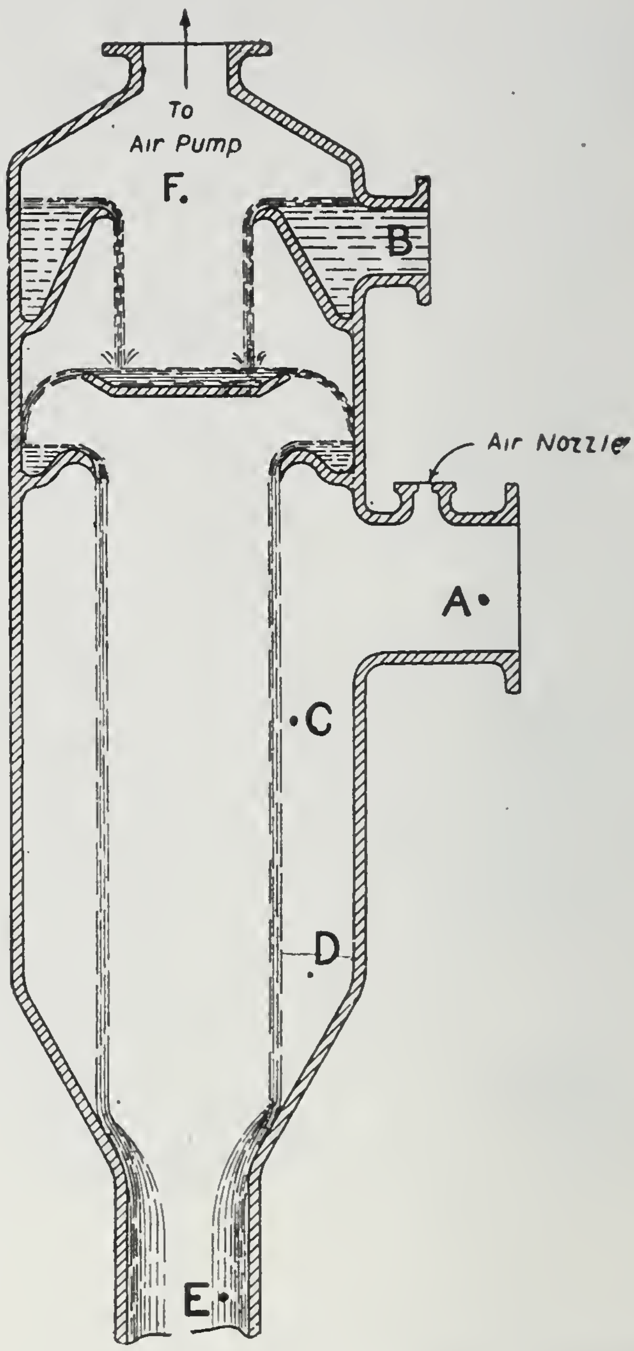

Fig. 2. Location of Thermometers in Experimental Condenser.

The manner in which even a very small quantity of air 'spoils the vacuum'' becomes vrey clear from a study of the temperature distribution in the condenser.

Temperatures were measured at points, *A, B, C, D, E,* and *F,* (Fig. 2). In the case of most efficient condensation the tem-

perature at A and E would read the same. In a test with no air in the steam, the thermometers at A (steam inlet) and E (tail pipe) read, indeed, within a few degrees of each other, with the thermometers at C and D reading between. As more and more air was admitted, the temperature at E did not change, but that at D, C and A changes. That at D rose a little, C more, and A the most. At first thought it is surprising that in spite of the admission of apparently hotter steam, the temperature of the tail water should remain constant; but, as a matter of fact, the steam contains no more heat than before, in spite of its higher temperature, because it contains more water than before.*

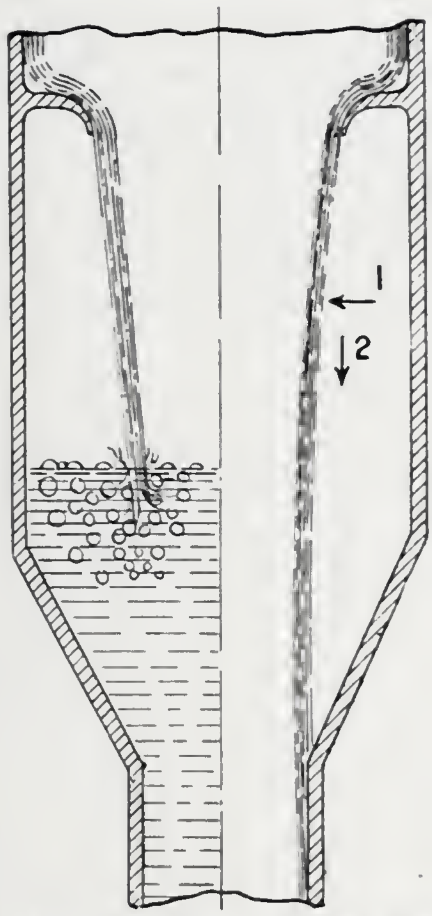

Fig. 3. Air Path in a Jet Condenser.

In a condenser which takes steam from an engine or turbine, the tail water temperature would rise with the addition of air to the steam, because the dropping of the vacuum would cause a greater steam consumption for a given load on the prime mover.

If we neglect for the present the normally slight pressure drop between the steam entrance A and the air pump nozzle, we can say that the pressure in the condenser is constant everywhere. Since the steam is saturated, dropping of its tempera-

*The line of throttling is the "constant total heat" line.

ture means a reduction of its pressure; but since the total pressure is constant, the air pressure must increase from *A* towards *D*. (It is known from Dalton's law that total pressure equals partial air pressure plus partial steam pressure.) The air temperature at the air pump nozzle of a counter current condenser coincides with that of the injection water, hence the vapor pressure there is even lower than at point *D*. From this short study we conclude that the partial air pressure in a condenser increases rapidly towards the air pump inlet.

The question: "What effect has air in a condenser?" may now be attacked quantitatively. Evidently the weight of air entering in unit time must equal the weight removed in unit time, if equilibrium is to exist. The greater the density of air

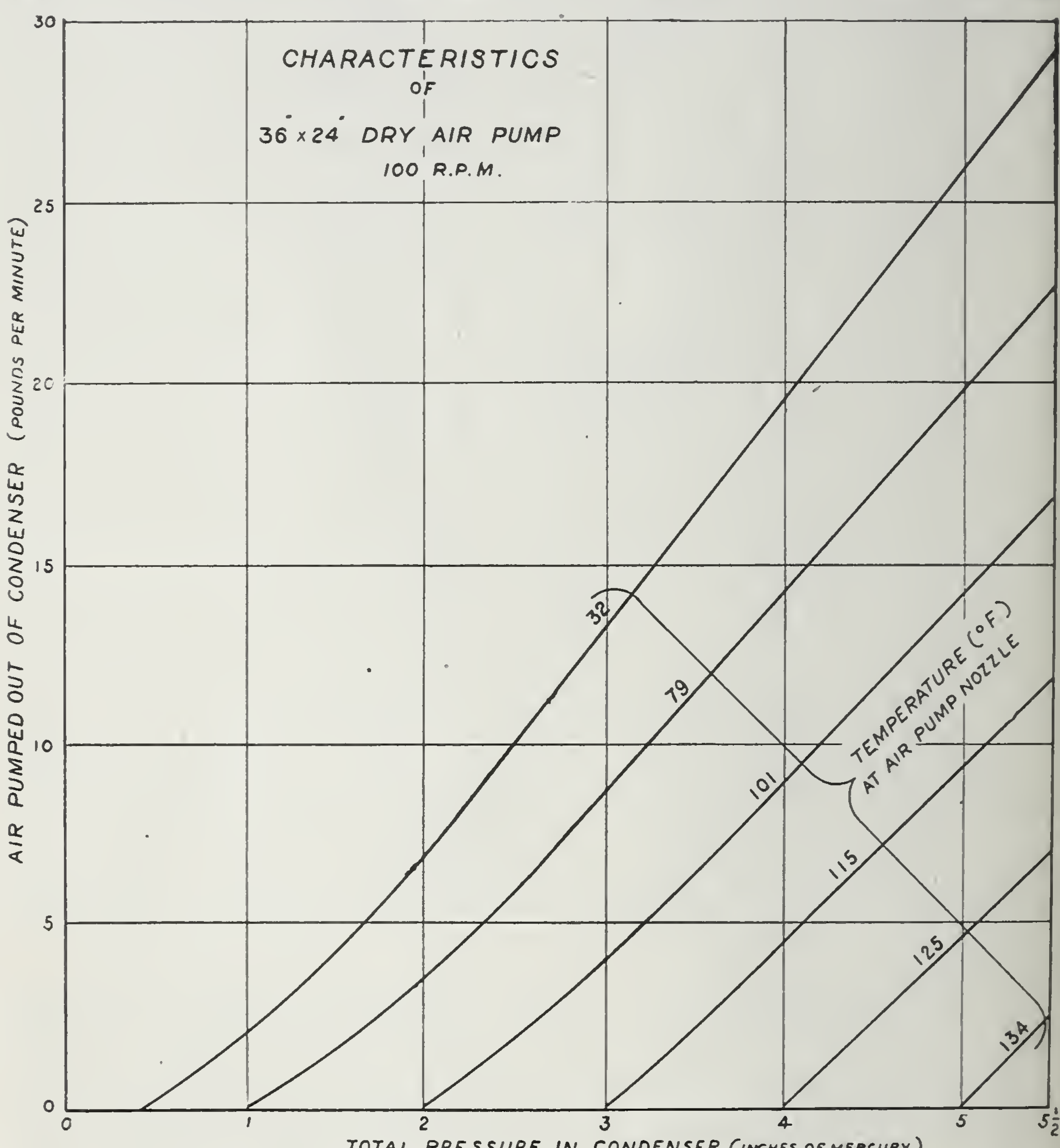

Fig. 4. Characteristics of 36 in. by 24 in. Dry Air Pump, 100 r. p. m.

going to the pump, the greater is the weight of air handled by the pump. Hence the air pressure at the air pump nozzle of the condenser adjusts itself automatically, so that equilibrium is established between air entering and air removed.

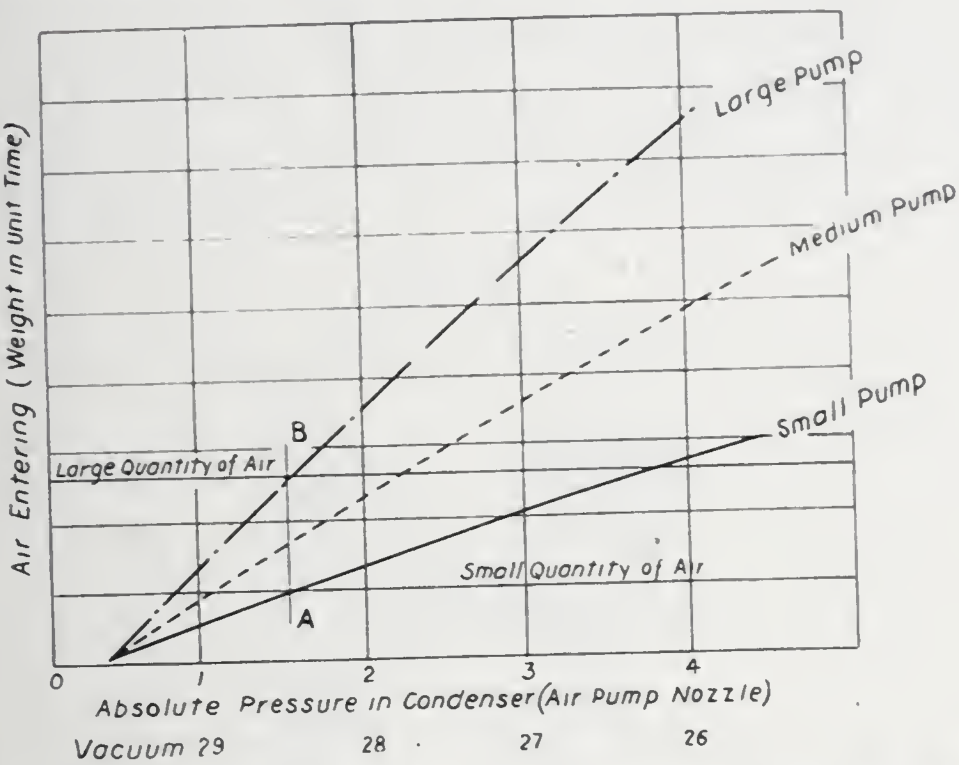

Fig. 5. Influence of Air Pump Characteristics on Vacuum.

Air is removed from the condenser not only by the air pump but also by the tail water, as will be seen from the following reasoning, which is borne out by facts. In Fig. 3 air is carried with steam towards the falling water in the direction of the arrow. It is held against the water by the onrush of other steam and is carried along with the water in the direction of arrow 2. If the water maintains its velocity until the narrow section of the tail pipe is reached, some air sticks to it and is removed by viscious drag or entrainment. If, on the other hand, the water falls into a pool as on the left hand side of Fig. 3, the air is beaten into the relatively stagnant water out of which most of it rises back into the condenser in the shape of bubbles. For the removal of all the incoming air by entrainment, the water velocity must be very high and the water jets must be sufficiently subdivided to offer large entraining surface. Otherwise, very poor vacuum will result. Test data on this type of condenser was promised the author for this paper by a firm building it, but the data did not arrive in time. Since this method of air removal is somewhat out of the ordinary,

it will not be followed further, and it will be assumed that all of the air is removed by the pump.

The capacity of an air pump in pounds of air in unit time is expressed by its characteristic or its characteristics. The meaning of these words is best explained by reference to Fig. 4, which represents the characteristics of a reciprocating pump of good design but of rather short stroke. The ordinates represent weight of air pumped, the abscissae the absolute pressure at the intake nozzle of the air pump. On account of the space taken

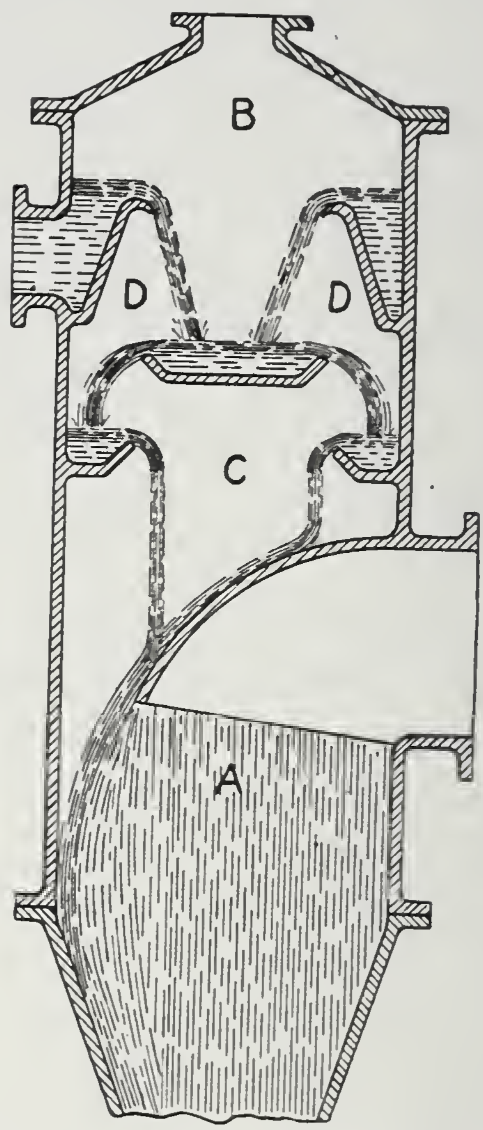

Fig. 6. Device in a Barometric Condenser.

up by vapor the weight of air contained in the volume unit of air saturated with vapor drops as the temperature increases at constant pressure. Hence there must be a different characteristic for every temperature. See Fig. 4. These characteristics can be found only by actual test. Unfortunately, builders of air pumps usually know very little about the characteristics of the pumps of their own make, or if they know them they do not publish them. This is to be regretted, because it makes worse

the uncertainty surrounding the performance of condensers. As will be seen later, the condenser owner has no means of knowing how much air leaks in; neither has he any means of knowing how much he pumps out, unless he possesses the characteristics of the pump. The characteristics of air pumps which have been published, are all based on the pumping of dry air. The characteristics for air and vapor mixtures can be approximately derived from the former, but the result can, of course, be only approximation.

Suppose, now, that we had the characteristics of the air pump on a given condenser; then we could determine the pressure at the air pump nozzle for any amount of air entering in the manner indicated by Fig. 5. This illustration is based on the supposition that the temperature at the air pump nozzle is known and that there is no appreciable pressure drop between the air pump and the air pump nozzle in the condenser. The characteristics of three similar pumps of different size are indicated in Fig. 5 by the solid, dotted and dot and dash lines. Two rates of inflow of air are indicated (horizontal lines). No actual figures for size of pump or rate of air flow have been given because we are at present concerned with the method only. Evidently the same vacuum may be maintained in spite of different rates of air inflow, if corresponding air pump capacities are employed: compare points *A* (small air flow, and small pump) and point *B* (large air flow, large pump). Two difficulties arise in connection with the use of the characteristic for actual condensers: First, in parallel flow condensers, the temperature at the air pump nozzle is not definitely known; second, in counter current condensers the pressure at the air pump nozzle of the condenser may differ from the pressure in the condensing space proper. Taking these two difficulties in the order mentioned we find that in the parallel flow condenser the air and vapor mixture going to the air pump has the temperature of the tail water, or a slightly higher temperature. It is known from the first part of the paper that this tail water temperature depends solely upon quantity of steam entering and upon quantity and temperature of injection water, no matter what might be the pressure of air in the condenser, but the latter, by spoiling the

vacuum increases the steam flow, if the condenser serves a prime mover. Thus the temperature of the air and vapor mixture depends upon the rate of air inflow and air removal, and the rate of air removal depends upon the temperature of the air and vapor mixture. However, the problem of determining the vacuum in the condenser correctly could be solved by a few approximations, if necessary.

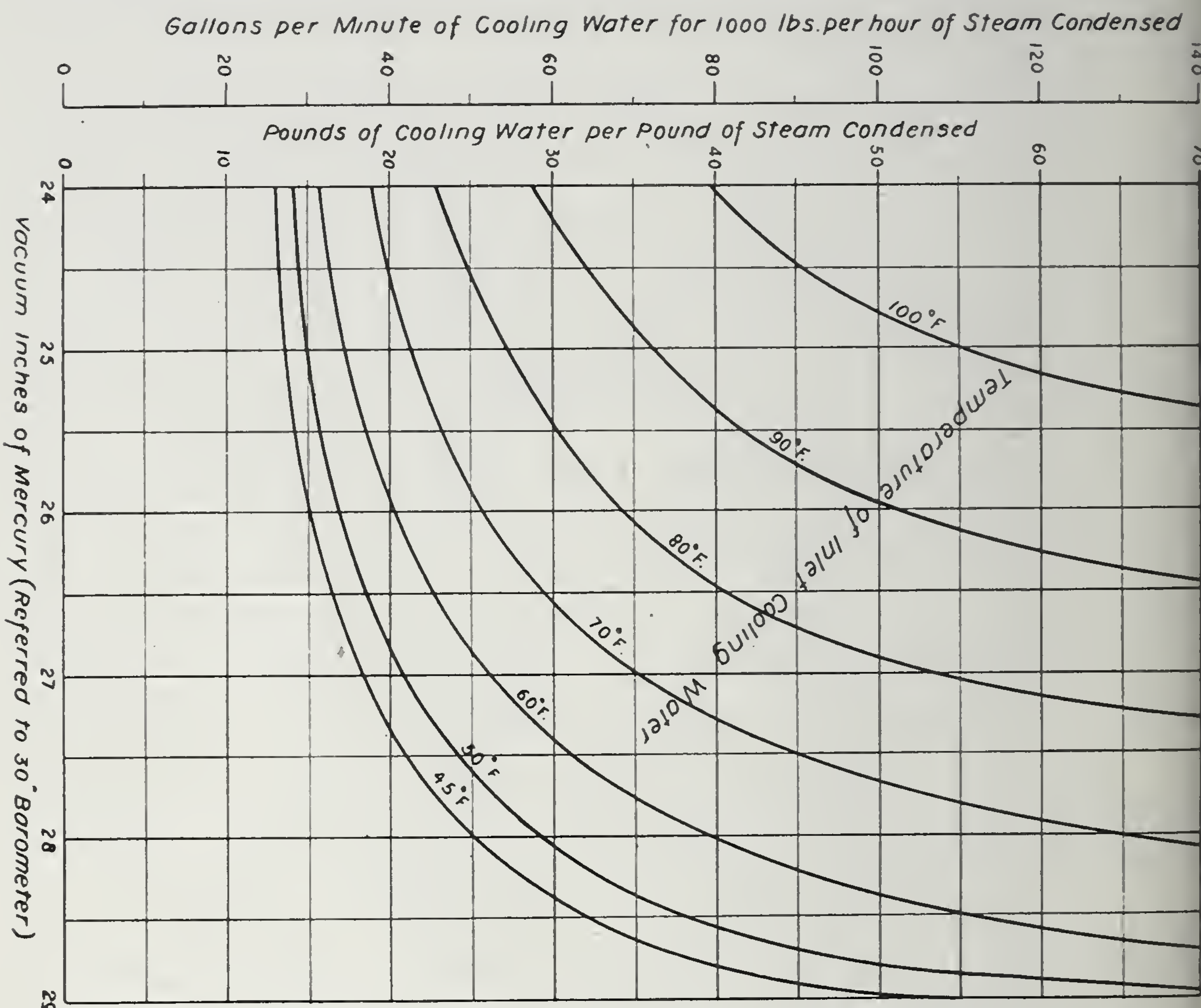

Fig. 7. Amount of Cooling Water for Condensers Based Upon 15 Deg. Fahr. Difference Between Temperatures of Exhaust Steam and Leaving Mixture.

The second difficulty occurs in counter current condensers, for which Weiss' type Fig. 6 may be taken as typical. In this type the pressures in *A* and *B* (that is in the condensing space and at the air pump nozzle) are determined by entirely different considerations. The lowest possible pressure at *A* is determined by the temperature of the outer layers of the tail water, which latter can be computed from the temperature and the quantity of the injection water and the quantity of steam. To save this computation, curves have repeatedly been drawn,

two of which are reproduced in Figs. 7 and 8 for reference. The pressure at B, on the other hand, is determined by the quantity of air flowing into space B and by the characteristic of the air pump, as explained before from Fig. 5. Evidently, the pressure in B must be lower than that in A, if air leaking in with the steam is to find its way to space B. In the ideal case there would be very little air pressure in A, it would gradually increase from A through C and D to B, whereas the vapor pressure would rapidly fall off on the same path. In practice, the air pressure at A may be smaller or greater than that at B depending upon the relative amount of air brought in by the water and by the steam, and on the resistance of the air through the water curtains or rainfalls. The latter should be so arranged that they allow the passage of air from A to B, but not the passage of steam, and this must be accomplished for a considerable range of water flow and of air coming in with the steam. If, in this type of condenser, the rate of water flow is gradually decreased, while steam flow and air pump velocity are kept constant, a point is reached where the water curtains or rain falls present sufficient opening to the steam to have some of it flow to space B, raising the temperature at the air pump nozzle. This rise in temperature means the use of a higher temperature characteristic for the air pump, and consequently a drop in vacuum, see Fig. 5. A study of the methods of preventing this occurrence, or of rectifying conditions if upward steam flow has set in, belongs to the specialty of counter-current condensers and exceeds the limits of this paper.

I have dwelt upon this point at some length, because so many conflicting opinions are heard on the influence of air pump capacity in counter-current condensers. In this connection I might mention that in certain condensers of this type, in which the water curtains are heavy, variation in pump displacement has much less effect than it has in parallel flow condensers. Increased air pump capacity raises the place of condensation from A to C, or even to D, so that the original resistance of the lower water curtains to flow of air is replaced by resistance to the flow of steam without much change of partial air pressure in C, although the vacuum at B may rise considerably. It suffices to call attention to this fact without discus-

sing the specific heaviness of water curtains, with which it occurs, because such a discussion would have to consider questions of detail design.

Let us now turn from the subject of air removal to the even more interesting subject of weight of air entering condensers under normal conditions. This subject is, indeed, interesting; the views of the condenser builder and of the condenser owner are usually wide apart on this point.

Injection water carries up to 2 percent of atmospheric air by volume, which is approximately 1/400 percent by weight. If, under average conditions, 50 weight units of water are required to condense one weight unit of steam, then the weight of air entering with the injection water is 50/400 or ⅛ percent of

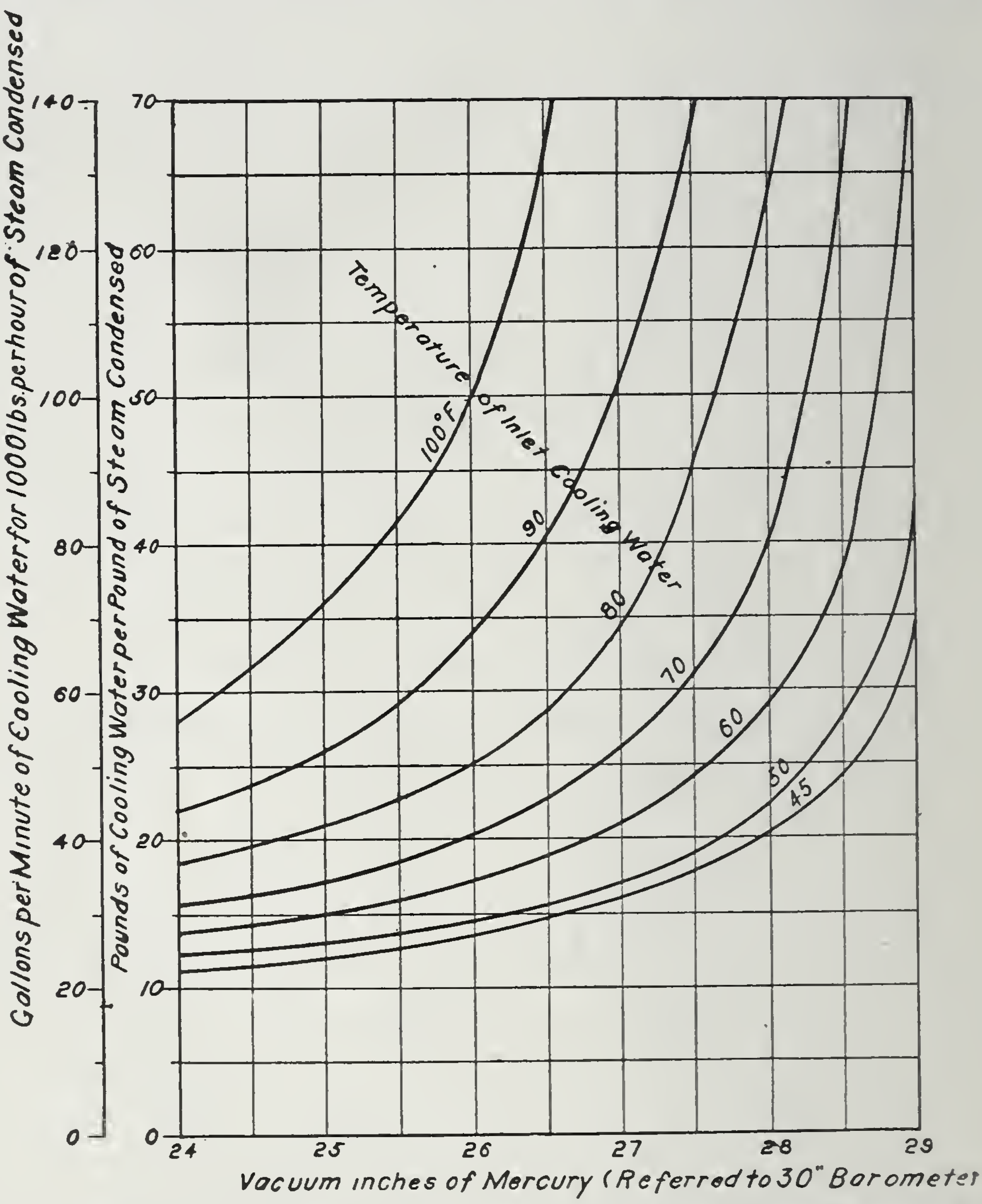

Fig. 8. Amount of Cooling Water for Condensers based upon 5 Deg. Fahr. Difference Between Temperatures of Exhaust Steam and Leaving Mixture.

the weight of the steam. Not all of this air is removed by the pump, because some air stays in the water even at the low pressure of the condenser. The weight of air coming in with the steam from the boiler feed water is usually negliible. Additional air enters the condenser with the steam on account of leaks. The weight of air which is normally expected to enter in this matter may be found from average air pump capacities. These range from two to four times the quantity of air entering with the water, so that the difference, which is one to three times ⅛ percent (that is ⅛ to ⅜ percent) of the steam weight, is expected to enter through leaks. If more enters, the vacuum must drop. Let, in Fig. 4, the pump be so proportioned that it maintains 28¼ in. of vacuum with ⅛ percent (of the steam weight) air in the injection water and ⅛ percent in the steam. Then if 1⅛ percent of air comes in with the seam, the pump will have to remove five times the original weight of air. If the temperature at the air pump nozzle in the condenser is maintained at 79 deg. Fahr., the vacuum would drop from 28¼ to 26¼ in., if everything else remains the same. In a counter current condenser the vacuum will drop even more on account of the resistance of the water curtains and on account of pressure drop in the pipe leading to the air pump. In a parallel flow condenser the rise of temperature caused by the drop in vacuum will augment the drop because a "higher temperature" characteristic will have to be used. The resulting vacuum would be "off-the-map" in Fig. 4, and would be in the neighborhood of 23 in.

Tests of condensers show reasonable uniformity in the effects of air leaks. Fig. 9 shows a curve derived from tests on a Mesta barometric condenser, and Fig. 10 shows a curve showing the effect of air in a Westinghouse Le Blanc condenser. It will be noticed that with one percent of air by weight in the exhaust steam the vacuum is exceedingly poor. These results are confirmed by the experience with surface condensers related by Mr. Orrok (Proceedings of Am. Soc. Mech. Engrs., 1912) in which one percent of air spoils the vacuum.

From our knowledge of air pump characteristics, we judge that one percent of air need not have any more influence upon the vacuum than ¼ or ⅛ percent provided that the air pump

is made large enough and that a free enough passage is provided in the condenser for the air. And from the standpoint of power plant economics it pays to maintain a high vacuum even at the expense of high cost of air pump operation. The trouble still remains where to draw the line: Shall the condenser and pump be built for ⅛ percent leakage or for one percent

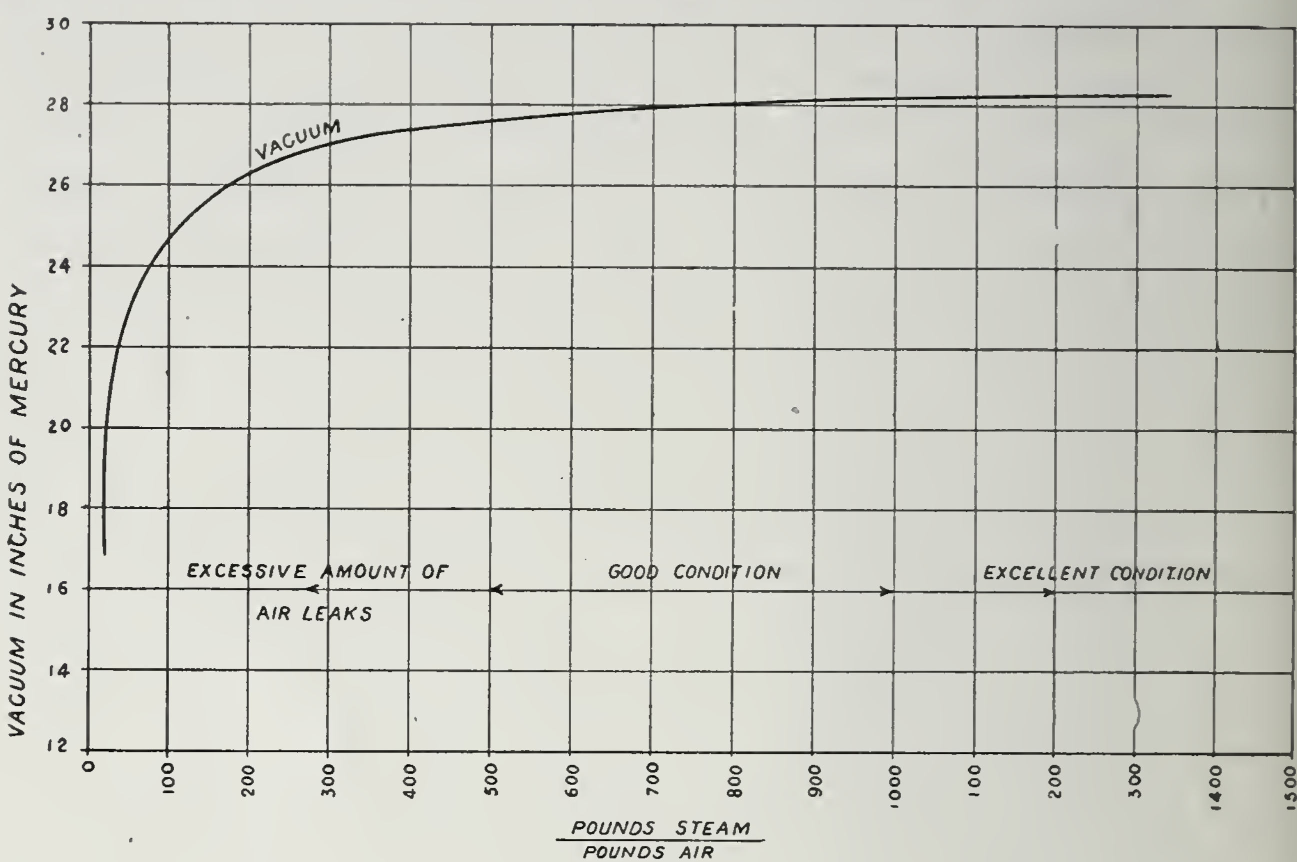

Fig. 9. Influence of Air in a Barometric Condenser with Reciprocating Pump.

and more? If we build them for one or two percent, hydraulic pumps will absorb an excessive amount of power beyond the requirements of feed water heating, and countercurrent condensers will have to have such large openings in the water currents that steam leaks through, if less air enters. This deleterious effect of varying quantities of air leakage has always given —and probably will always give—rise to litigation between condenser builders and condenser owners. Any unusual reduction in the vacuum convinces the user that either the condenser or the vacuum pump is out of order. Consequently he expects the builder to repair them free of charge. The builder, judging from former experience, claims that the trouble is due to air leakage. Condenser leaks are notoriously hard to find, so that the owner should, perhaps, not be blamed if he rejects any insinuation of leaks. But even after a condenser expert has

been sent by the builder and has found the leaks, the owner often maintains his attitude of doubt. Communications from several condenser builders, as well as personal experience, have proved to me this attitude of doubt on the part of the condenser owner. The proof lies in the refusal to pay for the services of the expert. The reasons held out for the refusal are most varied, but the underlying final reason seems to be this thought: "If such a little bit of a leak can spoil the vacuum in this condenser, it must be a mighty poor condenser. Hence the builder is responsible for our trouble."

All this quarreling could be avoided if an instrument existed for easily and correctly measuring the quantity of air in exhaust steam. Many years experience on both the builder's and owner's side of the fence has convinced me that such an instrument would be very serviceable. Reciprocating and rotating dry air pumps have been used as measuring devices; their discharge can be cooled and then run into a gas holder, or through gas meters or orifices (Creighton's air gauge). However, such arrangements are usually inconvenient and are not readily applied in practice; neither do they locate the leak, because air may come in not only with the steam, but also with the water or through leaks in the air pump line.

Furthermore, the measuring of the discharge of air from hydraulic pumps is difficult. For this reason I have for several years experimented with exhaust steam analysers or air detectors. Although these experiments have not been successful I shall briefly describe the principle upon which I worked and the difficulties encountered, in the hope that somebody else may be able to do better.

If a mixture of air and vapor is compressed from condenser pressure and temperature to atmospheric pressure, and is then chilled to freezing temperature, practically all of the vapor is condensed, and the air is left over. This simplicity of principle is coupled with a multiplicity of difficulties. First, it is difficult to get a representative sample of exhaust steam into the measuring vessel. It may be thought that a pipe, leading from the main exhaust through the sampling vessel to the air pump, would cause a copious flow of exhaust steam. Sometimes it does, but usually it does not, because small leaks in these necessarily

temporary connections cause a flow of air both ways; that is, from the leaks towards the air pump and towards the exhaust main. An air detector shows under these conditions most any amount of air from ½ percent to almost 100 percent, depending upon the skill of the operator and upon the tightness of pipe connections or rubber hose with which he works. After a truly representative sample has been obtained, the difficulty arises of compressing it in a transparent vessel without any admission of air. Fig. 11 shows one of the forms of vessel which I used. The sampler, after being filled with air and vapor

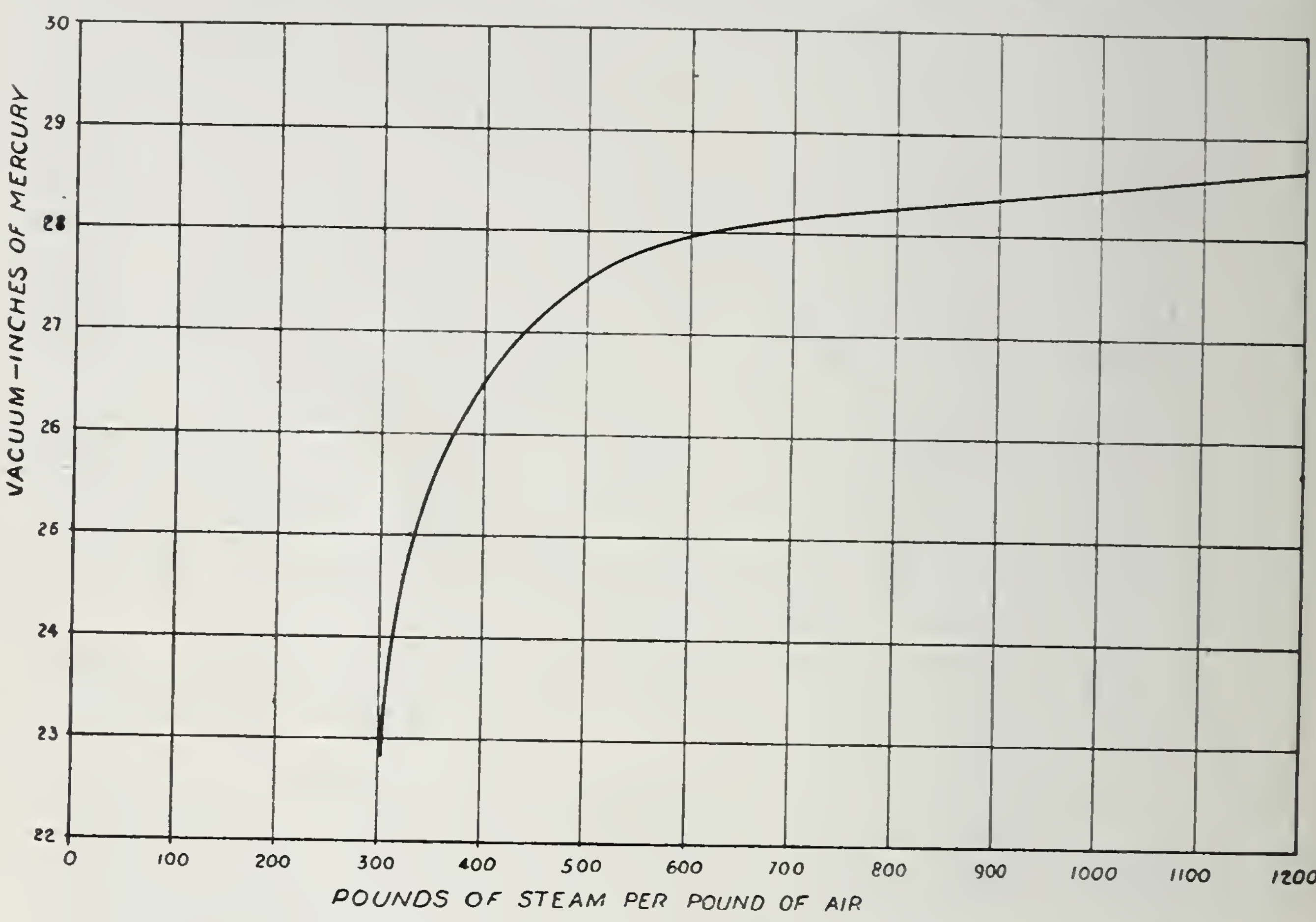

Fig. 10. Influence of Air in a Low Level Jet Condenser with Hydraulic Pump.

mixture, is immersed in mercury and the lower cock is turned slowly. A hole is provided at *B* for the purpose of allowing the air in the blackened space to be replaced by mercury before communication is established with the interior of the vessel. Indications are, that it is not all replaced, but that small bubbles remain which expand and rise into the sampler, as soon as the cock is opened to it. The quantity of air, after compression of a representative sample, is only 1/10 to 1/5 percent of the volume of the sampler, so that for measuring purposes the top must be made almost capillary. Small impurities, such as grease

(from the 3-way cock) rubber, (from the tube) or dope (from the pipe connections), make the indication of the mercury in the capillary tube very uncertain. All of these features taken together make this form of air detector a workable piece of laboratory apparatus, but a very poor instrument for power plant use.

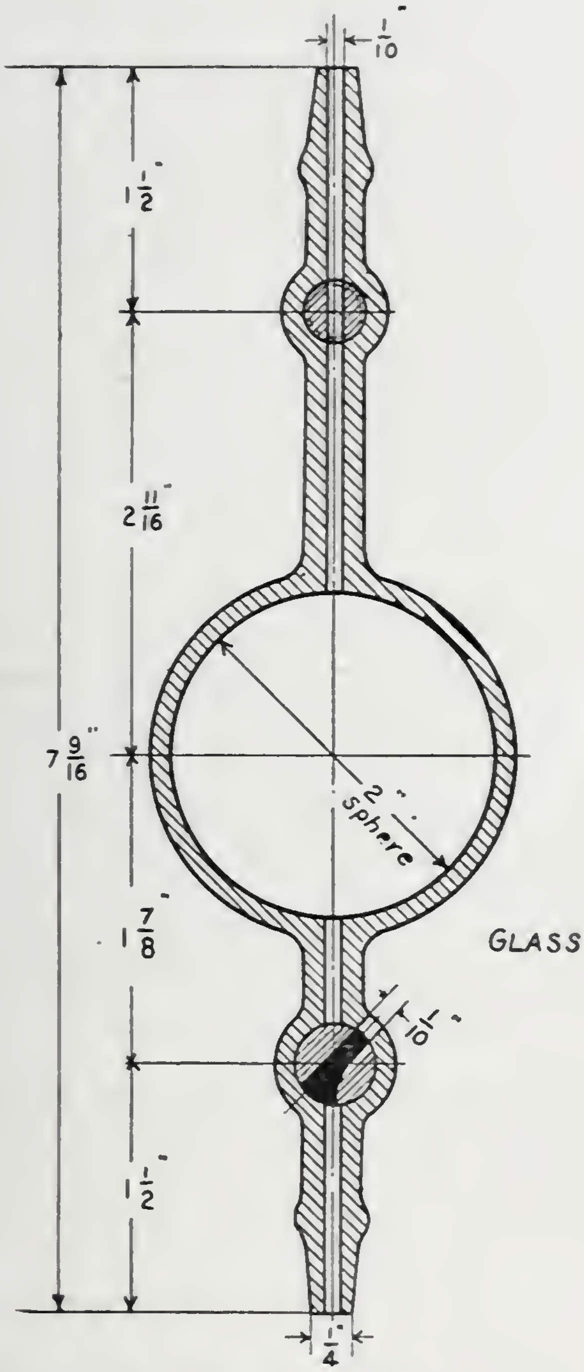

Fig. 11. Air Detector.

Leaving the subject of air in condensers, I may say a few words on the influence of sub-division of injection water. If water falls in a thick or heavy sheet or jet, the inner part, or core, is not heated up to the temperature of the surrounding steam, even if the latter be free from air. However, the particles constituting sheets or jets seldom fall in parallel lines;

usually there is a vibratory motion inside the sheet or jet which brings the inner particles to the outside and the outer particles to the inside. With air free steam, condensation is exceedingly rapid, so that a moderate amount of sub-division is sufficient. Additional sub-division of water, not dreamed of by the designing draftsman, is often produced by the steam impinging upon the water. Observation through the glass windows of the experimental condenser at the Carnegie Institute of Technology (Fig. 1), revealed the fact that the steam blew the sheets and jets of water literally to atoms, thus producing a vast condensing surface in a small space. That condensation was completed in a very small space was proved by this test: The tail water level was gradually raised in the condenser by partly closing a valve in the tail pipe until the tail water touched the steam pipe. No change in the vacuum could be noticed although steam flow and water flow were quite heavy compared to the size of the vessel.

In experimental work of this sort, one test suggests another, and I have planned several re-arrangements of the "insides" of the condenser. Since I have not yet made enough tests on the influence of interior arrangement of weirs and nozzles on the vacuum, I shall reserve this subject for another communication to the Society provided I find enough facts of interest.

In trying to gather confirmation of my own experience from various condenser builders for this present paper, I found most of them quite unwilling to part with any information whatsoever. Within the last two years I have been in the shops of every condenser builder of reputation in the United States and have discussed the various phases of condenser design and operation with their engineers, and I was astonished to find that large sums of money were spent by each concern individually for finding out facts already known to a competitor. A little co-operation and interchange of information would help all of them.

In conclusion. I wish to thank the American Sheet and Tinplate Co., the Mesta Machine Co.. the Armstrong Cork Co., the Hall Steam Pump Co., the Connersville Blower Co., and the Carnegie Institute of Technology for their co-operation in furn-

ishing or loaning material for this set of tests on condensers and air pumps.

DISCUSSION

Mr. Karl Nibecker:* I have read with much interest Prof. Trinks' most valuable and instructive paper on "The Effect of Air in Jet Condensers". I think we are especially indebted to him for this paper. from the fact that there seems to be little or no authentic information upon this most important question. Many of us have probably had considerable trouble with jet condensers and have never fully appreciated the exact effect of air leakage upon the vacuum produced by a condenser.

It would be interesting if Prof. Trinks would give us further information as to the type of air pumps which he used in determining the characteristic curves of the pumps, as shown in his paper. There seems to be considerable discussion at the present time concerning the value of flash ports in air pumps, and it therefore, is of considerable importance to know to which type of pump Professor Trinks' curves apply.

I would like to know what thickness of water was flowing over the various weirs in the experimental condenser, for the inlet water pipe appears to be very small. It would also be of value to have relative data with various thicknesses of water flowing over the weirs in the condenser.

Figure 6 exhibits the Weiss type of condenser as being typical of countercurrent apparatus and is compared to the condenser shown in Fig. 2. Figure 2 is not specified as a countercurrent condenser, although it would appear to be practically the same as Fig. 6, the only difference being the introduction of the deflecting steam nozzle. Referring to Fig. 6, the author states that the pressure at B is determined by the quantity of air flowing into this space and also the characteristic of the air pump.

In speaking of Fig. 2, Prof. Trinks assumes that the pressures at A and F are the same. I am at a loss to know why the pressure at F in Fig. 2 should not be higher than the pressure at A for the same reasons which he gives for Fig. 6.

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It would appear as though there must always be a pressure drop in passing through the sheets of water. It is most important to design the condenser so that the sheets of water shall not be excessively thick, and at the same time, they must not allow sufficient passages so that the steam may enter the space F.

I recently conducted some tests on a condenser where the drop in vacuum from the air pump nozzle to the steam inlet nozzle was 0.66 in. of mercury. This excessive drop, I believe, was due entirely to poorly designed weirs and insufficient condensing area at the base of the vessel. In a condenser with weirs properly designed, the drop in vacuum has been found to be less than ½ in. water gauge.

We all appreciate the difficulty of keeping the connections from the prime mover to the condenser absolutely tight, and when the difficulty of operating a condensing plant is considered, it seems to me that an air pump should be used of considerably larger size than most manufacturers seem to think necessary. I have seen many plants where the air pump was amply large for an absolutely tight line, but had no reserve capacity to care for the slightest air leak. On large lines, small air leaks are exceedingly difficult to locate, the most satisfactory method being, I believe, the use of a small flame produced by a taper or candle.

The author states that the air pump should be designed to handle two to four times the amount of air brought in by the water. It seems to me that it would be better practice to make this eight to ten times and contemplate operating the pump at very slow speeds. By this method of installation when air leaks are developed during operation, the pump speed can be increased and a reasonable vacuum maintained until such time as the pump can conveniently be taken off for repairs. In modern steel mill practice, we all know how important it is to keep the plant running until the week's end shut down. If the pumps are installed larger than would seem necessary, it will be found to greatly facilitate the operation of the plant.

The measurement of air delivered by an air pump is exceedingly difficult and can probably best be accomplished by means of a nozzle on the discharge of the pump.

For determining the amount of air in exhaust steam, I have

endeavored to use the air detector as mentioned by Prof. Trinks. The instrument which we used was constructed as shown in Fig. 12. *A* was connected to the line from which the sample was to be drawn, using a short connection. A sample tube was placed in the line, being constructed similar to the standard A. S. M. E. sampling tube, placing no holes near the edge of the pipe. *C* was connected to the air pump suction, thus causing a flow through the apparatus. The water jacket was filled and a stream of water passed through from *D* to *E* having a temperature of the vacuum in the steam line. After enough steam had flowed to produce a fair sample, the two cocks were closed. Ice water was then run through the jacket to condense the steam, the end *B* being placed in a mercury cup, the mercury rising into the measuring burette. It would seem as though this apparatus should give good satisfaction and as though we should have little or no trouble determining the amount of air in the sample.

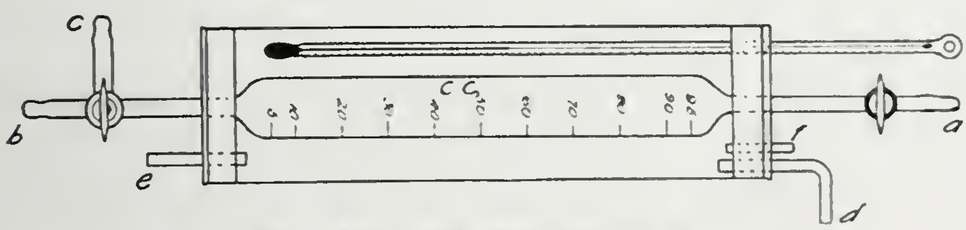

Fig. 12. Air Detector.

As mentioned in Prof. Trinks' paper, the difficulties are many, and require a very skilled operator to obtain consistent results. By very careful manipulation and exercising every precaution to have tight connections and lines, we have been able to obtain results that are consistent and which check fairly with the amount of air which we should expect to find in the exhaust steam.

It must be understood that the apparatus shown is difficult to manipulate and must be handled with the greatest care, using every precaution to insure absolutely tight joints. Under these conditions, we feel that the results are reliable. We have encountered practically all the difficulties in using this apparatus which Prof. Trinks mentions, but they have gradually been overcome.

The Author: Referring to Mr. Nibecker's remarks on the fact that Figs. 2 and 6 are practically the same, and that con-

sequently the pressure inequalities of Fig. 6 pertain likewise to Fig. 2, I admit that he is right, and yet I think his remark out of place. I say in my paper with regard to Fig. 2: "If we neglect the normally slight pressure drop for the present, etc." This temporary neglect is justified in any analysis for the purpose of avoiding complication resulting from the study of too many variables at one time.

MR. W. E. SNYDER:* I do not make any pretense to discuss the subject matter of this paper, as I have not had much time to study it, and what effort I have been able to put on the paper has not been very effective, because of the absence of the figures used as illustrations. I will, however, attempt to present a short discussion, using the subject of the paper as a topic.

During the past twelve years, I have had general charge of the installation of a number of different kinds of condensing plants, and also general supervision of the operation of about 75 separate condenser installations, which includes almost every type of condenser that has been made during the past 20 years and of capacities varying from that of a small jet condenser required for a 200 k. w. power unit, up to a central condenser of 250 000 lb. of steam per hour capacity, serving a number of large engines.

The sum total of all the condenser experiments which would result from installing and operating so many different types, sizes and kinds, under different conditions, causes me to say, that the one feature of condenser installations which gives the most trouble to the men who have to operate them is, lack of air pump capacity. This is a condition which is, or was, apparent in a variety of forms in more than three-fourths of all the installations of which I know anything. Some places it has been eliminated and conditions are satisfactory; at other places it has not been eliminated and conditions will not be satisfactory until it is.

It has always seemed to me that the companies designing condensers have not made enough of a study of the operating conditions, and in consequence make the air pumps too small. The attempt is made by means of paper and lead pencil to

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determine the size of the air pump which must be installed, let us say with a large barometric type central condenser, which is serving a number of engines. The results are bound to be disastrous. There was some excuse for this condition when central condensing plants first began to be put in, and the data relative to operating conditions were very meagre. However, as experience began to accumulate, it does not seem to me that the condenser companies' engineers learned what they should have learned from their installations—or at least they were not willing to increase the estimated air pump capacities, as the results of actual use indicated that they should be increased. I remember one installation which we made about ten years ago. The engineer of the company, about to obtain the contract, told me that the air pump capacity he would furnish would be exceptionally large for the capacity of the condenser; after I had gone into the matter, I made him increase the capacity about 30 percent above what he considered was exceptionally large. Since that time we have put on new cylinders, again increasing the capacity of the air pump by 50 percent. This is a true illustration of the air pump capacity as estimated with pencil and paper, and what was actually required in practice.

Now, I am aware of what the condenser engineer will say in regard to this; he will say that the increased air capacity was required because more air was allowed to leak into the system than he contemplated when he estimated the air pump capacity. This is probably the correct reason too for the increase of size necessary. One other reason may be mentioned, and that is, that some condenser designers estimate that the water will take a certain percentage of the air with it out of the tail pipe, and when a condenser is put in operation this does not occur, or if it does happen, it requires so much water to take out a small quantity of air that it is a most wasteful way of removing the air. (I am speaking now with reference to different types of barometric condensers.) However, the fact remains that there is more air to be removed from the system than was estimated by the condenser engineer and the result in general is, that a large number of condenser installations are operating with a vacuum of from 21 to 24 in. in place of from 25 to 28 in., as it should be.

This condition always reminds me of an incident about which I once read: A poor washwoman went to a physician because she was sick. After the doctor had examined her, he asked her about her circumstances and she told him she had to make a living for herself and six children by doing washing. After some further questioning, the doctor prescribed—she must have absolute quiet, spend most of the day in bed and have plenty of nourishing food. At the end of a couple of weeks she went back to the doctor, in about the same condition as she was before. He asked her if she had followed out his instructions implicitly, and she replied that she had not, because she couldn't. He simply brushed the whole matter aside by saying, if she did not propose to follow his instructions she need not expect to be improved. This is the experience that we have had with some condenser installations, the condenser engineer being the physician. He would make a diagnosis that there were air leaks, and consequently too much air in the condenser system and the leaks would have to be stopped. Then would follow various discussions with the superintendent of the works and his mechanical department, with a great deal of searching for air leaks and much general dissatisfaction, all of which might possibly result in a very small and temporary improvement in the vacuum. Later, conditions would become as bad as ever or worse, and there would be more work for the mechanical department, with very doubtful results. This is a condition which more than one superintendent of a works has had to deal with for years and during the time that he has had this condition, hundreds and possibly thousands of dollars have been wasted due to the poor vacuum on a number of large engines. It is the physician prescribing the impossible for the patient and then washing his hands of all responsibility, if the prescription is not carried out. This is the condition which makes me say that the worst trouble in my experience in handling condensers is, deficient air pump capacity, and that this comes about because the condenser companies persist in proportioning their pumps to handle a theoretical quantity of air—or at least a very small margin above the theoretical quantity—whole in the actual practical operating conditions of works, it is not possible for the mechanical men to keep a condenser system so perfectly

tight that the conditions which the condenser engineer had in mind can be attained.

Just to illustrate what a difference in practice there is among different condenser companies in proportioning air pumps, and to show what the proposed user of the installation has to contend with, the following comparison is given of four bids on the same specifications for a condenser plant of 110 000 lb. of steam per hour capacity. These bids were put in in the early part of 1912, so that at that time there was enough known about central barometric condenser plants to render it unnecessary for anybody to guess at the air pump capacity required. The following is the detail giving the comparison:

Make	H	I	J	K
Air pump size	30 × 18 in.	34 × 21 in.	42 × 30 in.	30 × 24 in.
R. P. M. at 300 ft. per min. piston speed	100	86	60	75
Cu. ft. displacement at 300 ft. per min. piston speed	1472.7 cu. ft.	1891.5 cu. ft.	2886.3 cu. ft.	1472.7 cu. ft.
Cu. ft. displacement at 60 r. p. m.	883.6	1329.5	2886.3	1177.0
Percentage using *J* as standard	30.6 percent	46.1 percent	100.0 percent	40.8 percent

This comparison shows that when the pumps proposed were running at the same piston speed of 300 ft. per min., the displacement of one was just about double what was proposed by two other companies, and the one giving the highest displacement, run the lowest number of revolutions. This latter point is better illustrated by the last two lines of the comparative table, which assume that all of the pumps ran 60 revolutions a fair speed for efficient operation), though, of course, a higher speed could be run if desired. This comparison shows that the pump proposed by one company, if at 60 revolutions would have a displacement of only about 31 percent of the largest pump proposed at the same r. p. m., and the other two pumps less than 50 percent of the largest. In other words, here were four experienced condenser builders, supposedly, all proposing to make a certain condenser installation, yet the air pump capacity proposed, when put on an equal revolution basis, which is the fairest comparison for the operator to make, as it is the best comparison of the durability of the pump, shows that one com-

pany proposes less than one-third of the capacity of the largest; another company about 41 percent and another 46 percent of the largest. It is fair to assume that the one proposing the largest air pump was not making a wild guess, because that company has quite a number of installations in successful operation. My own opinion is, that the largest proposed air pump was not large enough, and if this was the case, what about the others?

Now, if these smaller pumps had been put in, this condition would have come about: First, there would have been a period of poor vacuum, explained both by the condenser builder and the condenser purchaser by saying, that this is a new installation, just starting up and in consequence has a number of leaks which are to be expected in any new installation. There would be some small activity on the part of the condenser builder representative and a great deal of strenuous work on the part of the mechanical department in the works in which the condenser was located, until their resources had been exhausted, to find and stop leaks. After the excuse of "leaks incidental to a new system" had exhausted its efficacy, and would no longer explain the condition, and the vacuum remained poor, a controversy would begin between the condenser man and the purchaser. The condenser man would keep repeating "air leaks" were plainly evident; the purchaser would defy the condenser man to find them and there would be more activity on the part of the mechanical department of the works. This controversy would continue with variations of different kinds, until finally the customer would get tired, pay for the installation and it would drag along with 22 to 24 in. vacuum, possibly less. This is no fanciful case, but is a small chapter out of a rich experience.

Now the secret of a satisfactory condenser installation is simply to make the air pump large enough to take care of leaks which are necessary, and which are bound to exist under operating conditions. So long as a condenser system has to be nursed and petted in order to keep a fairly respectable vacuum, it is a foregone conclusion that the air pump is too small—provided, of course, that there is sufficient water and the piping has been properly put up. The point which it is desired to make is, that

the installation must be proportioned so that good results are continuously obtained with a minimum amount or even lack of attention on the part of the operating force. If there is a loss of vacuum as soon as the master mechanic turns his back, it is pretty conclusive evidence that the air pump is too small, because there is bound to be some leakage of air around piston rods, valve stems, through gaskets, etc., which it is not practical to prevent. This leakage is variable, and, of course, produces worse results during the summer. It is simply nonsense to proportion an air pump so that it necessitates continual vigilance on the part of the master mechanic or his assistants, and requires that an ordinary piece of apparatus, which should operate with practically no attention, must needs be given more supervision than the most complicated piece of mechanism. Even when leaks are located by means of a torch, or various other devices which have to be used, it is not always possible or advisable to repair them. For instance, suppose a leak is occurring through metallic packing on a 16 in. piston rod. Is the master mechanic to be compelled to take out the rings and put in new ones? If he does do this, he may have trouble getting new rings to fit the rod: or he may have more trouble with the new ones than with the old ones. So it is in case of a leak through a gasket in a large pipe. It makes a very difficult and expensive job to take out a large gasket to repair a small leak, and the point which I am making and want to emphasize is, that the air pump should be made large enough to pump out some excess air over and above the theoretical quantity, so that some of these leaks can exist without destroying the vacuum.

The paper of the evening admits the advisability of planning the air pump capacity large enough, but says the difficulty is, to know where to draw the line. In other words, of course, it is not possible to keep on increasing the size of the air pump in order to take care of leaks which the mechanical department do not want to bother repairing. I do not think, however, that this difficulty is very formidable, provided condenser companies would make a study of the operating conditions of their condensers. At all events, in proportioning a condenser air pump, I would prefer to use the rule said to have been devised by the late John Fritz in designing a fly wheel—to figure it out, double

it and then add some. It is better to have the air pump too large rather than too small; then when the condenser plant is new and in good condition, the pump can be run slowly, and this can also be done during the winter months. During the summer, or when leaks develop, the pump can be run faster until the leaks become bad enough to necessitate repairs. I think investigation of condenser plants will show that there is a reasonable limit in the size of an air pump, and still not make it necessary to trouble about the leakage which it is not practical to prevent, in operating the system. If proper attention is given to this matter in making an installation, the mechanical department of the works in which the condenser is located, will be saved a great deal of hard work and the company owning the condenser will be saved a great deal of money, due to the fact that good vacuum is maintained continuously.

Another difficulty in connection with the operation of condensers, and which is being gradually eliminated, is that of driving both the air and water pumps by means of one prime mover. It does not take many words to make this statement, but it has taken a long time in some works to eliminate a condition which should never have been permitted to come about in the first place. Tying air and water pumps together makes it impossible to vary the one independent of the other. If it is desired to pump more air, it cannot be done without pumping more water and vice versa. One good arrangement for a barometric condenser is, to have an electrically driven centrifugal water pump and a reciprocating steam driven air pump.

There is some mention made in this paper about the capacity of the air pump being affected by consideration of the quantity of steam required to heat the feed water. In getting an air pump of large enough capacity for a condenser plant, I do not think it advisable to pay any attention to the need for a certain quantity of exhaust steam from the air pump. In some installations with which I am familiar, the heater is from 500 to 1000 ft. away from the condenser plant and it is not practical to use the exhaust steam to heat feed water, though, of course, it is advisable to do this if it can be done. It is much better, however, to exhaust the air pump into the condenser, if it is located too far away from the heater, rather than decrease its size in

order to save steam. The quantity of steam used by the air pump is a very small percentage of the total steam condensed, and a gain or increase of vacuum of 3 or 4 in. on several large engines is wholly out of proportion to the small increase in the steam consumption of the air pump. Therefore, my suggestion is, to make the best use possible of the exhaust steam from the air pump, but not to allow this to have any bearing whatever on proportioning the air pump.

I previously referred to the fact that some leakage of air into the exhaust system under vacuum is bound to occur. I want to suggest a few general rules for keeping this leakage down to a minimum: All large pipes in an exhaust system should be made of heavy plate, well riveted; the thickness of the plate, of course, depending somewhat on the diameter of the pipe, but varying from $\frac{1}{4}$ in. or $\frac{5}{16}$ in. for 20 in. pipe to $\frac{7}{16}$ in. or $\frac{1}{2}$ in. for 60 in. pipe. This plate work, riveting, etc., should be constructed as carefully—though, of course, the seams will not need to be as strong—as if the pipes were to contain high pressure steam. If a thoroughly good job of riveting is done and the joints well caulked, one long and important step toward the prevention of leaks will have been taken. Another thing is, to keep the number of flanges as low as possible, and where flange connections are necessary, to use every care in putting on the flanges and bolt them up with a good gasket between. Another point is, to make all exhaust piping accessible so that every part can be tested for leaks, and if any leaks are found, it is possible to get at them and repair them. I have seen exhaust pipes buried in out of the way places so that it was impossible to make any kind of a test, and even if leaks were found, it was not possible to get at them to repair them. Such conditions can just as well be avoided when an installation is being made.

With good riveted piping, properly put in for the main lines, and all joints made up properly in the branch lines, the other places where leaks are apt to occur are around engines or turbines, where the pipes are connected, and at the stuffing boxes. Even with the best care, there is some leakage bound to occur here, and the only salvation is plenty of air pump capacity. (Of course, in all of this discussion I am referring particularly to condensers used in steel works and other kinds of steel manu-

facturing plants, and do not refer to the more favorable conditions of large. modern power houses.) There are other ways by which air gets into exhaust lines, one of which is, when a boiler is filled with water, very often the vent cock is not opened, and the air that is in the boiler is trapped in the upper part of the drums, carried over with the steam and finds its way to the condenser; thus causing the air pump to make a great many strokes to get rid of this air. Of course, the remedy for this is apparent.

In this discussion, I may seem to over emphasize the importance of large air pump capacity. However, I do not think it possible to over-emphasize this point, because, after a large sum of money is expended to make a condenser installation, it seems absurd to plan the installation so that it is not possible to obtain the maximum return on the investment. It was found by careful test at the 59th Street Station of the Interboro Rapid Transit Co. of New York, that an increase of vacuum of from 25 to 28 inches caused a reduction of 8 percent in steam consumption of the engine. This gives some idea of the increased saving effected by improvement in vacuum, and it is just as easy to carry 26 to 28 in. vacuum in a good condenser installation of a steel works, as it is to carry 22 to 24 in., provided the installation is made properly; the first cost is but very little more and the operating cost is also but very slightly increased, while the return on the investment resulting from good vacuum as compared to poor vacuum is very much larger. In addition to this increased return, which is largely accomplished by a large air pump, this large air pump will also relieve the mechanical department of the works from a great deal of worry and trouble. It is for these reasons that I emphasize the necessity for plenty of air pump capacity, and urge the condenser builder to proportion their air pumps to suit practical working conditions; and not in accord with some theoretical principles, which make no allowance for practical operating mill conditions.

The Author: I agree with Mr. Snyder that air pumps should be quite large, and did say so in my paper, but I also said: "Where are we to draw the line?" Shall condenser builders figure with ½ percent of air in the steam, or with one or

two percent? A very successful condenser salesman told me that he always visited the plant to which he tried to sell a condenser and "sized it up". If everything about the plant was well kept, he bid on a small air pump; if things were not properly kept, he bid on a large air pump.

If Mr. Snyder and other engineers in a similar position will specify how much air is coming in with the steam, the condenser builders will have something to go by, and the bids will be uniform. In the absence of such information they must guess at the length of the exhaust lines and at the efforts which the "mechanical department" will make to keep the lines and packings tight. It is really a wonder that their guesses are not farther apart than the figures which Mr. Snyder gives as a deterring example.

Any statement of the form : "Air pumps are not large enough, and should be made larger" is of just as little value as the clause which is found in condenser contracts: "Such and such a vacuum is guaranteed, provided that the lines are reasonably (or commercially) tight." What is reasonably tight? The two statements: "The air pump is not large enough" and "The lines are not commercially tight" are a worthy pair of brethren.

One of the most fruitful sources of air leaks lies in rod and shaft packings. I have seen piston rod packings on low pressure cylinders so loose that the inrush of air blew a torch out. Steam turbine engineers realize this fact and equip their packings with steam, or water, seal. The engine builder is in a less fortunate position, because every master mechanic has a hobby concerning metallic packings, and resents any interference. Besides, the engine builder does not care so much, because a slight drop in vacuum does not affect engine economy nearly as much as it affects that of the turbine.

My remarks about the use of exhaust steam from condenser auxiliaries for feedwater heating referred to central station practice only, and not to mill practice.

Mr. Alex. L. Hoerr:* In reply to Prof. Trinks I would like to say that Mr. Snyder's point regarding the size of the air pump is probably this:

For years condenser builders have been furnishing con-

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densers and air pumps of standard sizes to handle given quantities of steam, in spite of the fact that operating experience has repeatedly shown the air pump capacity to be inadequate. Mr. Snyder believes that the builders should have profited by this experience and gradually increased the pump capacity until satisfactory service was secured under the conditions usually encountered.

Mr. J. B. Shatzer:* We regret very much that it was impossible for us to get our data and material here in time for Prof. Trinks to embody it in his paper, but with the permission of the Society we will present what we have at this point in the discussion.

In his paper Prof. Trinks mentions jet condensers in which the condensing water is sub-divided and passed through the condenser at a high velocity, and for which no air pump is required.

In the condenser which I wish to bring before you this principle is employed, and before going into a discussion of the performance of the condenser it would be well to explain its action.

Figure 13 herewith shows a sectional view of this type of multi-jet condenser. The steam enters the condenser either at the top or at the side inlet, and the water is admitted at the inlet to the left, and is maintained at a pressure of 9 lb. in the water head. This gives the water a high velocity when passing through the several nozzles which are set so that the jets converge in the throat in the lower part of the condenser. The steam when it enters the condenser is evenly distributed around the jets by means of a series of vanes called the combining tube. The steam coming in contact with the jets is condensed, while the air is entrained by the jets and carried off through the tail pipe. This condenser is capable of carrying vacuum up to 29 in. of mercury.

It was our intention to make complete tests upon condensers to determine under given conditions the following data: First, the number of pounds of water to condense a pound of steam under different vacuum and water temperature conditions; second, the performance of the condenser as an air pump, that

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is, the amount of air the condenser will handle without admitting any steam into the exhaust; third, the amount of air the condenser will handle when condensing its full quota of steam.

Owing to the fact that we have only recently had the use of our new testing plant, we were enabled to procure only the first and third of these points, namely, the water ratio of the condensers under test and the amount of air handled without admitting steam.

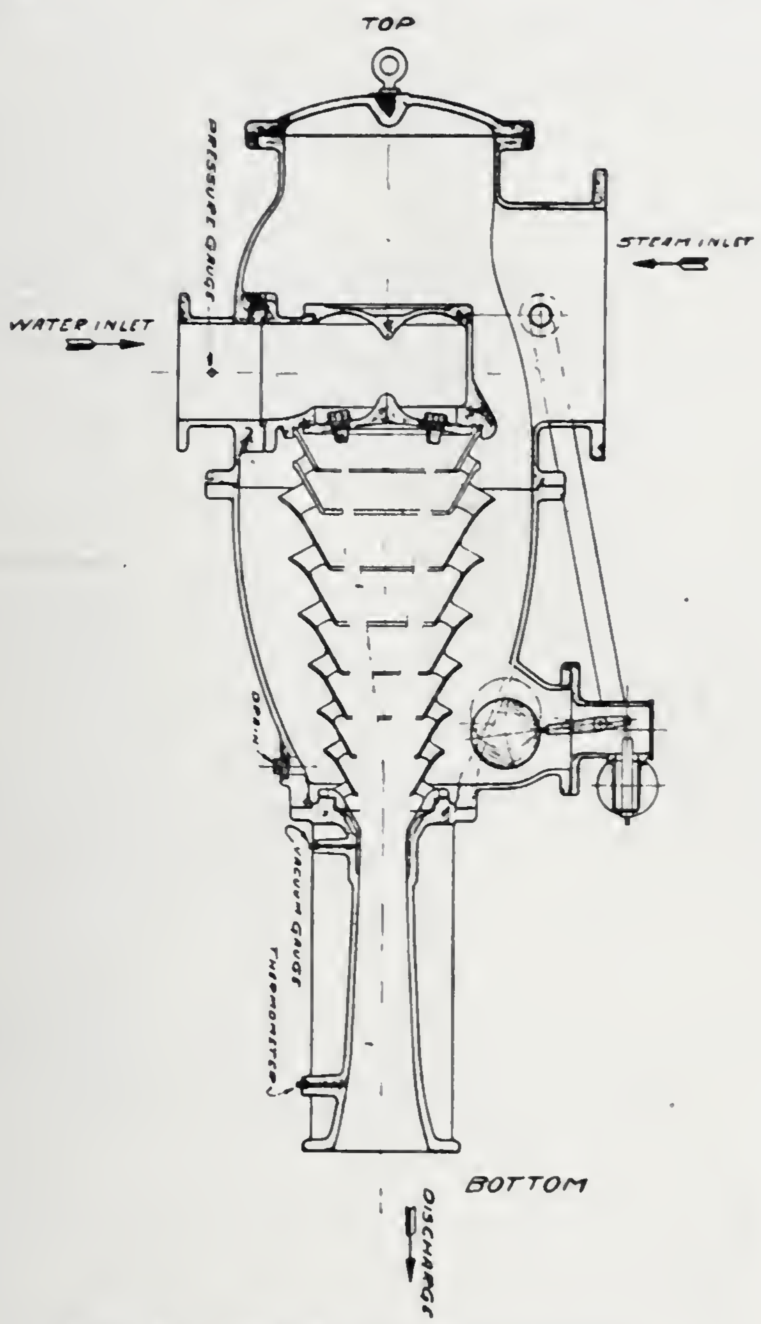

Fig. 13. Multi-Jet Condenser.

Figure 14 is a set of curves in which the vacuua are plotted against the number of pounds of water required to condense one pound of steam, each curve representing a different water temperature, namely, 60, 70, 80 and 90 degrees. It will be noted that these water ratios run on the average higher than those required for the ordinary jet condenser, and in most cases

the difference in temperature between the theoretical vacuum and the tail water is about 15 degrees, which difference is, of course, higher than that obtained by other condensers. In explanation of this we would call attention to the fact that the work ordinarily done by an air pump in a condensing system is in this case taken care of by the extra water passing through the condenser, the idea being that it is more economical to remove air by means of a highly efficient water pump than by an air pump of low efficiency.

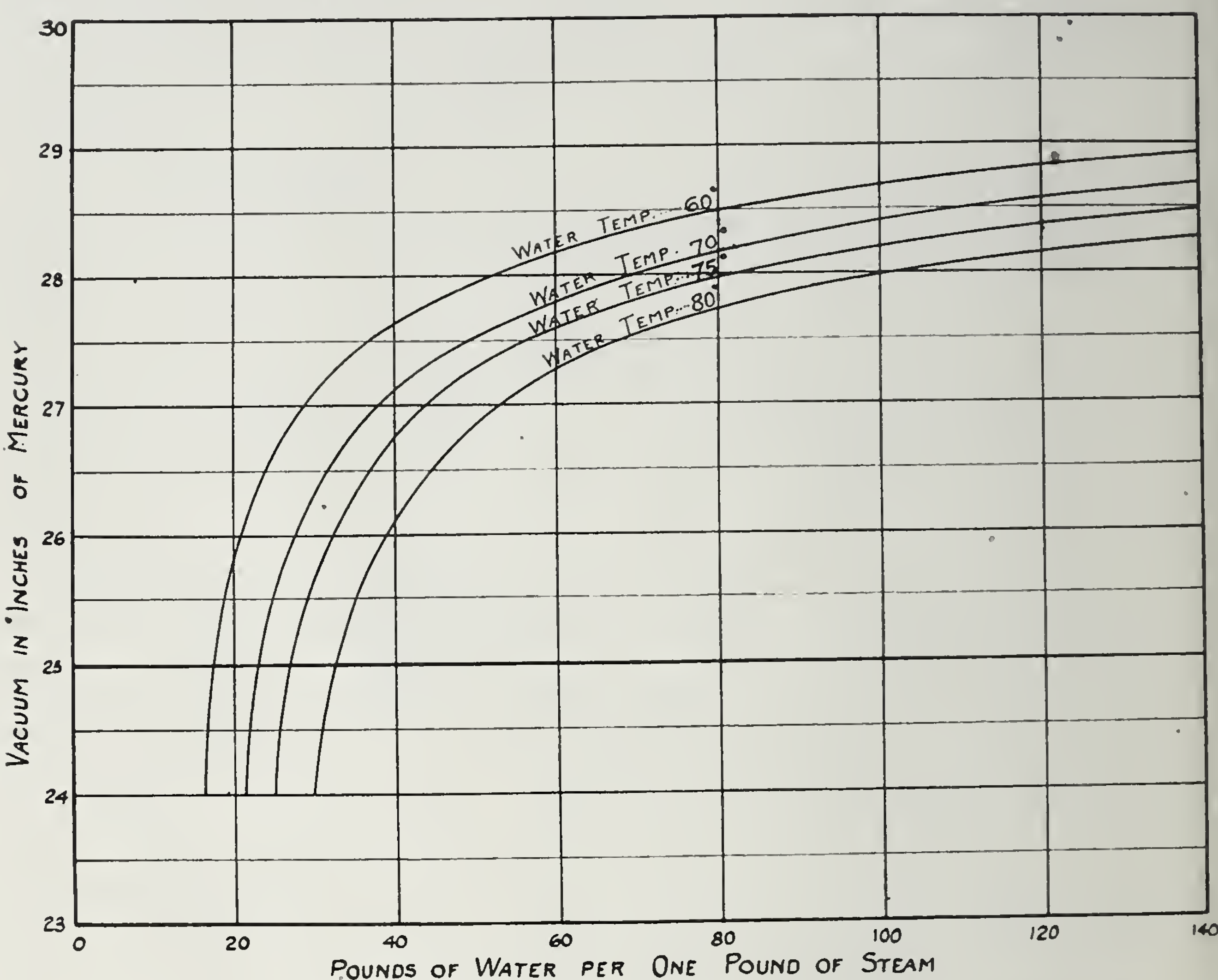

Fig. 14. Curves of Water Consumption in a Jet Condenser.

Referring now to the air handling capacity of the condenser we call your attention to the set of curves shown in Fig. 15. In these curves the vacuum in inches of mercury is plotted against the weight of air in pounds per minute admitted to the condenser without allowing any steam to enter the condenser. The condenser used on this test is what is known as the No. 38, which is capable of condensing 16 000 lb. of steam per hour; maintaining a vacuum of 28 in. referred to 30; and requiring 2200 gal. per min. of 70 degree circulating water. In the test the water

temperature was maintained at 70 degrees, and the outside air temperature was 75 degrees, while the pressure of the water in the head of the condenser was varied from 9 to 12 and to 15 lb.

From these curves it is readily seen that the air handling capacity of the condenser increases with the pressure maintained on the condensing water, and that at a pressure of 15 lb. in the water head, it is possible to admit 0.7 lb. of air per

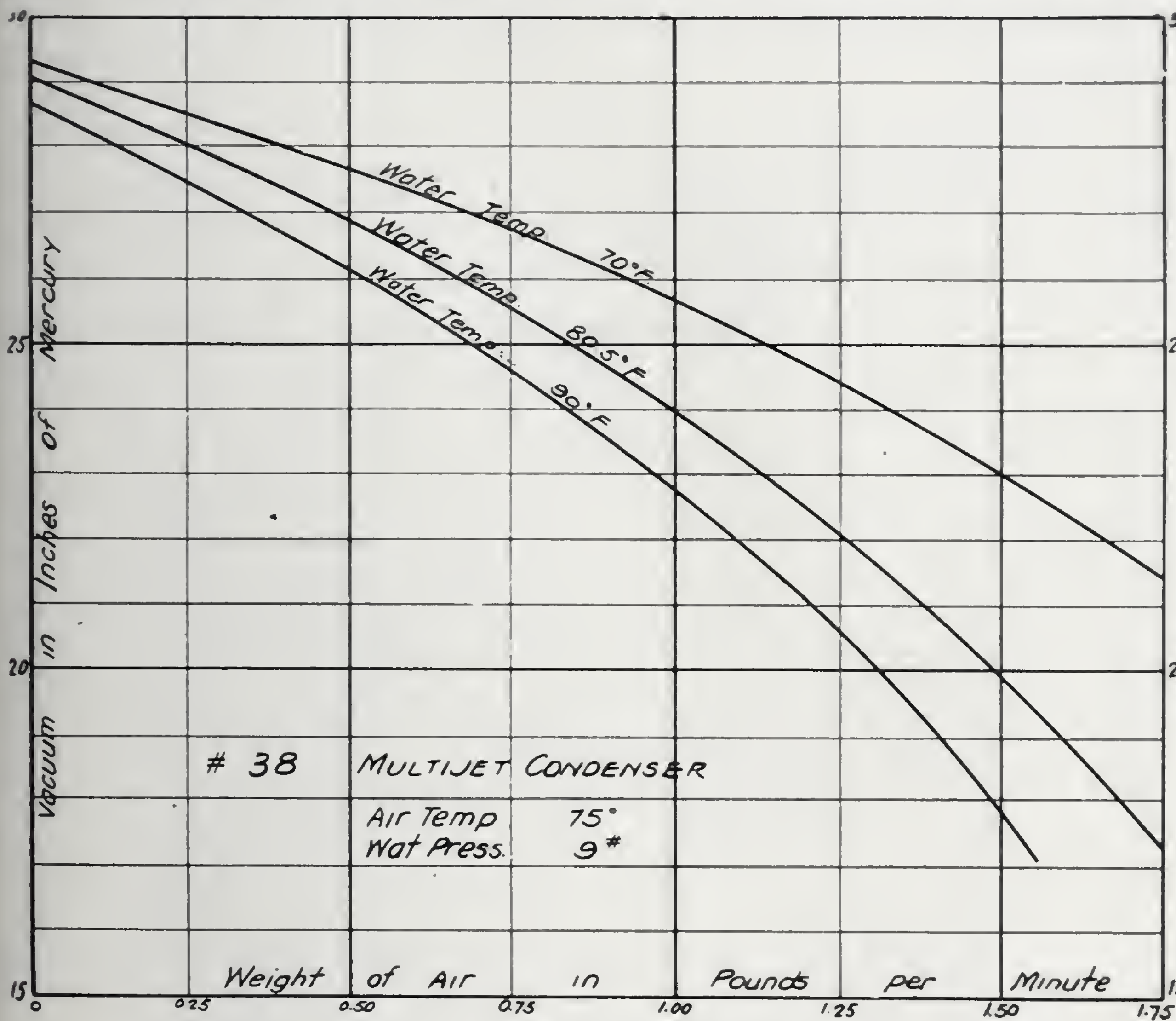

Fig. 15. Air Handling Cacapity of a Jet Condenser.

minute and still maintain a vacuum of about 20 in. This, of course, is not a large air handling capacity when compared to an air pump requiring the same amount of power, but on the other hand this condenser is not advanced as an air pump alone.

In Fig. 16 curves of a similar nature were plotted except that in this case the condenser used in the test was of much smaller capacity and was the No. 33 which is capable of condensing 8000 lb. of steam per hour, maintaining a vacuum of 28 in. with 1135 gal. per min. of 70 deg. circulating water.

The air temperature and the water pressure were kept constant, namely, 75 degrees and 9 lb., while the water temperature was varied from 70 degrees to 80.5 degrees and to 90 degrees. In this case it is seen that the air handling capacity of the condenser increases as the temperature of the condensing water decreases, and in this case it is seen that, with 70 degree water and a pressure of 9 lb.. the condenser is capable of handling 1.75 lb. of air

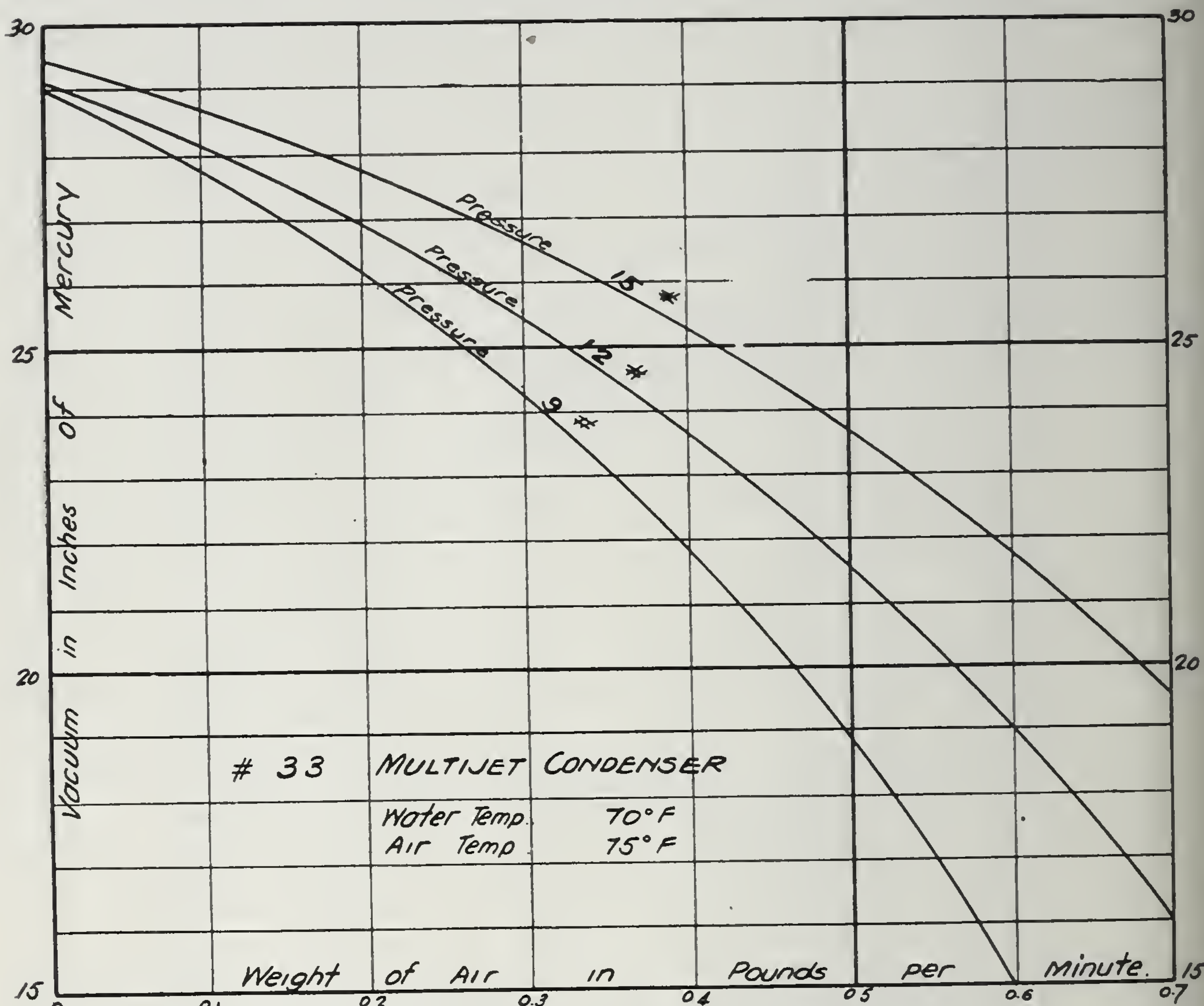

Fig. 16. Air Handling Capacity of a Jet Condenser.

per minute and maintain a vacuum of 21½ in. This does not agree with the results shown by the curves in Fig. 15, but this is due to the fact that these tests were run on condensers of dfferent size.

In conclusion we wish to call attention to the fact that these tests as run would place the condenser under the worst possible conditions as an air pump, the reasons being as follows:

The air entering the condenser through the steam inlet moves at a very high velocity (probably 600 ft. per sec.), and at this high velocity when it strikes the jets of water the tendency

is for the air to rebound and move in all directions. A very small portion of it clings to the jets and is carried off by the tail water. Now, if the air were admitted with steam the tendency would be for the steam to move uniformly towards the jets where it would be condensed, and in doing this the steam crowds the air against the jets and holds it there until the water drags the air away with it by viscous drag or entrainment. Therefore, the air handling capacity of the condenser when condensing steam would be considerably higher than when handling air alone.

MR. R. M. RUSH:* Prof. Trinks' remarks on steam sealed stuffing boxes were of particular interest to me, for the reason that the company with which I am connected has made some very interesting experiments along the line of carbon packing and steam sealed glands on turbines and engines.

The problem was an exhaust steam turbine operating in connection with an engine and governed entirely by the engine; that is, the turbine governor was not used when the combination engine and turbine set was in operation. The only difficulty encountered was that at partial load the vacuum would go back into the engine cylinder. That is, at, say, half load the turbine would operate between 10 in. and 28 in. of vacuum, and the engine would exhaust at a vacuum of 10 in. While this is not very high vacuum, the air leaks around the stuffing boxes of the engine would be so great that the vacuum would be interferred with in the condenser. By the introduction of carbon packing, the same as used on steam turbines; that is carbon packing rings—split in three parts and held together with a spring—it was possible to prevent the leakage of air along the engine piston rod.

Carbon rings will run closer to a shaft than any other material and it has often occurred to me that carbon packing might be used to advantage on engines and other reciprocating machinery. I do not know whether this has been tried in practice, but it works perfectly with steam turbines and I know of no reason why it would not work on steam engines. It seems to me that low vacuum, which seems quite common around steel

*District Manager, Kerr Turbine Company, Oliver Building, Pittsburgh.

mills, might be bettered by the introduction of carbon steam sealed packing on reciprocating units.

Mr. Nathan Owitz*: We appreciate that it is a fine thing to have a condenser with an amply large area for overload conditions, and an equally excellent thing to have an air pump capable of handling a larger quantity of air than the conditions under which it is to operate; in other words, to have the condenser and air pump larger than is really needed for the duty required. This is especially true for the air pump. There is one objection to this item, however, as it means that the purchaser will have to pay an increased price for the larger unit.

Speaking of the original paper that was submitted this evening, I want to mention a very important point which might set some of us to thinking. It was not so very long ago that condenser manufacturers did not think it necessary to break up the circulating water when it entered a jet condenser. It was thought, as long as an ejector effect was made possible by arranging a converging throat between the condenser cone and the tail pipe, that this would be the means of entrapping all the air that came into the condenser shell with the exhaust steam, through leaks and with the circulating water. Later very extensive and rather expensive experiments were made with a view to breaking up the circulating water into a very fine spray or rain. Some objections were made regarding this item at the beginning, for the thought was advanced that when the circulating water was broken up very fine it released all the air that was brought in with the circulating water, and instead of the air being taken off by means of the ejector effect, it liberated an extra quantity of air that had to be handled by the air pump. However, it was found that since an air pump was necessary to a good installation, from every conservative engineering standpoint, it was the function of the air pump to handle all the air and the result is that most prominent builders will refuse to figure on a barometric condenser that is to operate with a 28 in. vacuum unless an air pump goes with the machine.

The circulating water is broken into a very fine spray as the experiments showed that an intimate mixture between the

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circulating water and the exhaust steam is necessary to a good installation.

It was mentioned this evening that the condenser builders knew so very little about the behavior of a jet condenser and air pump that they guess at the equipment they offer to meet certain guarantees. In view of the fact that there is such a number of installations of this type of machine throughout the country that are meeting and exceeding guarantees every day, it would appear that the condenser builders must know a little bit about their equipment, or must be pretty good guessers. Surely, enough progress has been made in condenser practice to eliminate the guessing part of the question and I believe that condenser builders know what results can be obtained with certain machines when operating under certain conditions, especially when they are willing to make absolute guarantees covering their equipment.

We all know that most machinery is tested before final payment is made and when equipment falls down, the purchaser has a very good comeback. If the condenser builders do so much guessing and know so very little about their equipment as has been brought up this evening, then I think some of us would finally get into such bad financial straits that we would have to go out of business. Fortunately these conditions do not exist.

Taking for granted that the condensation of steam is thoroughly understood we find that we need, in order to obtain a high vacuum, the following factors:

First: Sufficient cooling water to abstract the latent heat of the steam.

Second: Such construction of the condenser as will insure ready transmission of heat from steam to water and full utilization of all the water.

Third: The withdrawal of the air at a temperature as low as possible and where the proportion of air to steam is greatest.

Fourth: Sufficient air pump displacement to dispose of the mixture of air and uncondensed vapor.

In ordinary jet condensers water and steam are admitted at the top of the condensing chamber and fall together to the bottom, where they are withdrawn by a pump or barometric column. The air present is removed either by the outgoing

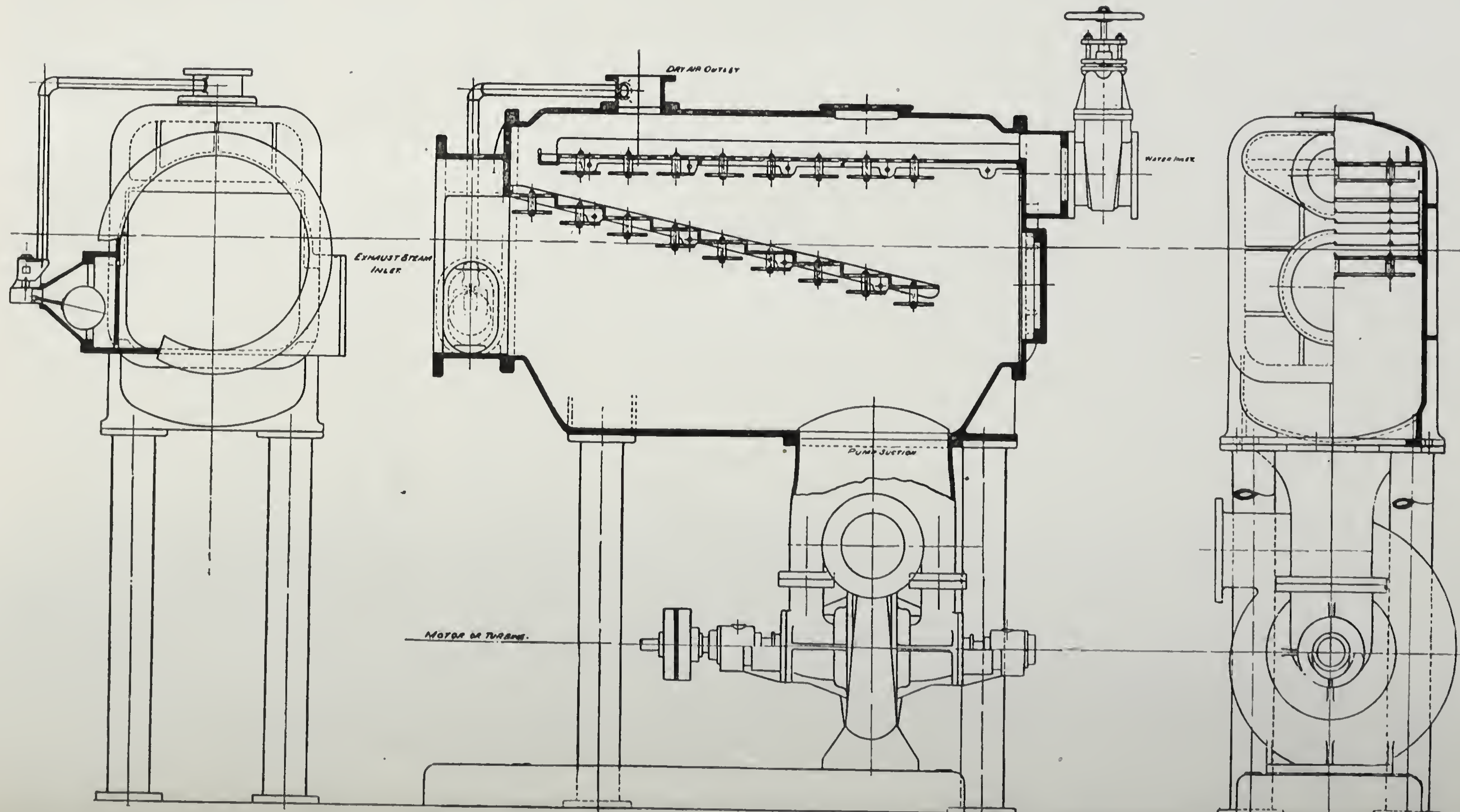

Fig. 17. Counter Current Type of Jet Condenser.

water which entraps the air and forces it to the atmosphere, or else an air pump is connected at the top of the condenser and the non-condensable gases removed in this manner. With the ejector type it is difficult to obtain vacuums of more than 25 to 26 inches, due to the fact that the water will only entrain a limited amount of air, unless the circulating water is delivered to the condenser under a greater velocity head and the amount of circulating water increased. In comparing the type of condenser that is guaranteed to maintain a vacuum of 28 in. without the use of an air pump to the type that is figured on using an air pump, it will be found that the water in the former goes to the condenser at a higher velocity head and that the quantity of water required is, in some instances, over 100 percent more than is required in the latter type. This means that larger pumps will have to be installed to operate in connection with the first type of machine mentioned and the charges for pumping will naturally be much greater. Most of the builders of the jet type condenser will not recommend condensers without air pumps, where a 28 in. vacuum is desired and some of them will not even quote on such an outfit.

On the other hand, where it is attempted to obtain high vacuum by connecting a dry air pump to the top of a condenser of this type, the temperature is relatively high and the proportion of air to steam in the mixture is very low, necessitating a pump of undue size. As will be pointed out in the latter part of this paper, low air pump suction temperature results in a great reduction in volume of non-condensable gases, because of the lower vapor pressure and correspondingly increased density of air at low temperature.

The primary advantages of a good jet condenser lie in the fact that it utilizes the heat absorbing capacity of the cooling water to the greatest degree, discharging it from the bottom of the condenser at almost the exact temperature of the steam, while at the same time outgoing non-condensable gases come in contact with the water entering at the top of the shell and are, therefore, cooled to the lowest temperature.

Thus, while the total pressure in the condenser is constant, the partial pressures going to make up this total pressure are so maintained in the top and bottom of the condenser as to

result in the highest economy. In the bottom of the condenser where high water temperature is desired, the total pressure is made up almost entirely of steam pressure. In the top of the condenser where it is desirable to have high partial air pressure so as to insure high density of the non-condensable gas, the low temperature of the incoming cooling water insures a low water vapor "or steam" pressure, hence high air pressure.

In the specific jet condenser, shown in Fig. 17. the cooling water can be discharged at exactly the temperature of the exhaust steam. The efficiency, therefore, may be 100 percent. The high efficiency at which a condenser of this type may operate is shown in the accompanying table.

RESULTS OF TESTS OF A JET CONDENSER

Vacuum Inches.	Absolute pressure. Inches mercury. Corrected for Barometer o1 29.9 Inches.	Corresponding temperature of exhaust steam. Degrees F.	Injection water temperature. Degrees F.	Outlet water temperature. Degrees F.	Difference in temperature between steam and circulating water. Degrees F.
28.65	1.25	85.5	44	85	0.5
28.7	1.2	85	44	85	0.0
28.75	1.15	83.5	44	83	0.5
28.7	1.2	85	44	83	2.0
28.75	1.15	83.5	44	80	3.5
28.75	1.15	83.5	44	81	2.5
28.65	1.25	85.5	44	80	5.5
28.55	1.35	88.5	44	87	1.5
28.75	1.15	83.5	43	79	4.5
28.75	1.15	83.5	43	76	7.5
28.6	1.3	87	43	82	5.0
28.6	1.3	87	43	82	5.0
28.7	1.2	85	43	82	3.0
28.65	1.25	85.5	43.5	82	3.5
28.75	1.15	83.5	43.5	83	0.5

As higher and higher vacuums are demanded in modern turbine plants, the temperature of the condensed steam has been necessarily reduced. In condensers so designed that the cooling water is discharged 15 to 20 degrees lower than the steam temperature, this has resulted in tail water of very low temperature, representing where the boiler feed is drawn from the condenser. an unwarranted increase of two to three percent in coal consumption. However, as the temperature of the tail water is always as high as is possible for the vacuum maintained, no loss in value of the boiler feed is sustained.

With increased consumption of cooling water in ordinary jet condensers a larger air pump and an increased power consumption by that pump would follow, from the increased amount of air brought into the condenser by the cooling water. As is shown in Fig. 18, a large proportion of the air removed from a jet condenser is brought into it, in solution with the condensing water. Assume for instance, that with a condenser in which the water rises from 70 to 100 degrees, the total air removed per minute is one pound. Referring to Fig. 18, let it be assumed that 40 percent of this, 0.4 pounds is brought in by the cooling water. If now the rise in temperature of the water

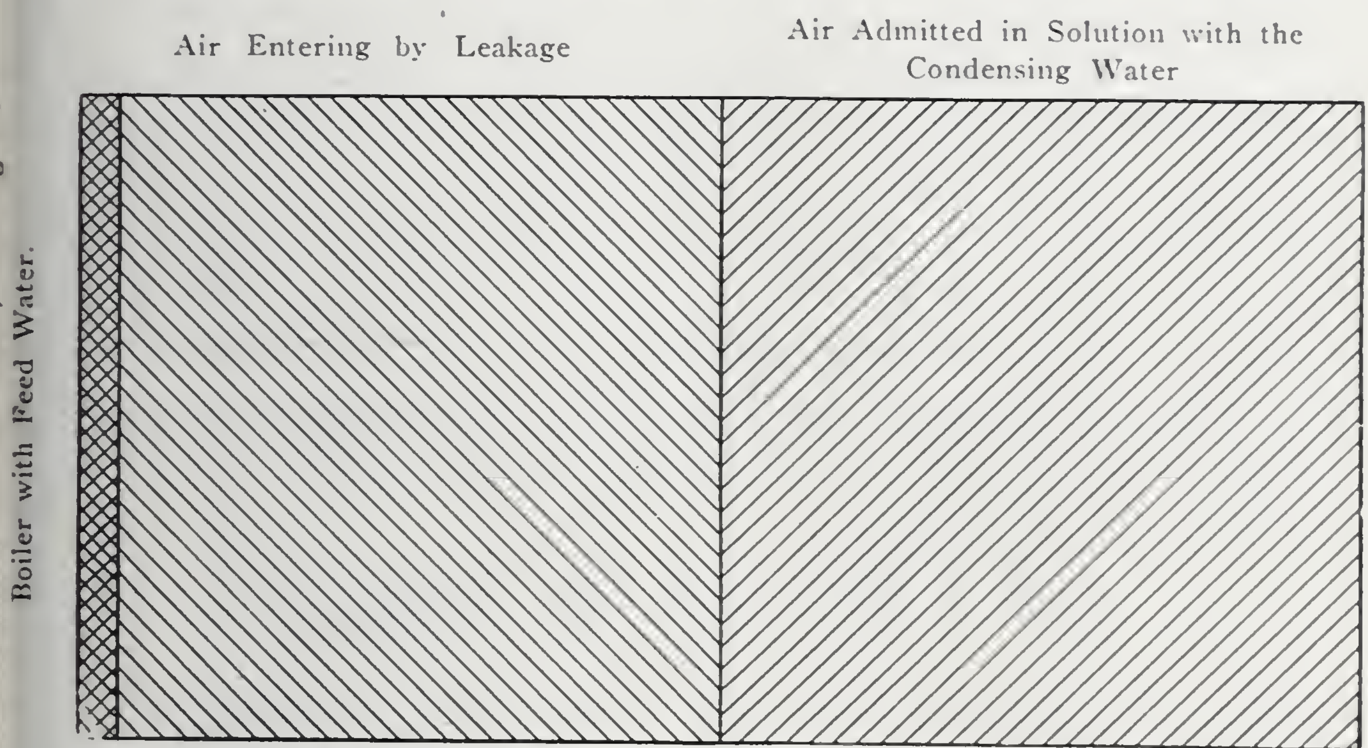

Fig. 18. Approximate Proportions in Which Air from Various Sources Enters a Jet Condenser.

were only 15 deg. instead of 30 deg., then twice as much water would necessarily be used and 0.8 pounds instead of 0.4 pounds would be brought into the condenser by the cooling water. Hence the total weight of air to be handled by the air pump would be increased from one pound to 1.4 pounds or 40 percent. Thus to maintain the same vacuum, an air pump of 40 percent greater capacity will be needed, to say nothing of the tail pump of 100 percent increased capacity.

The counter current type of construction of a jet condenser and the consequent cooling of non-condensable gases passing to the air pump at a low temperature, results in the load on the

air pump, to maintain a given vacuum in the condenser, being a minimum.

The great reduction in volume resulting from decreasing temperature of an air-steam mixture whose total pressure is constant as in a condenser, can be best shown by a typical example. Assume for instance, that the vacuum in a condenser is 28 in., or practically one pound absolute. This total pressure is the result of the partial pressure of the steam and of the air mixed with it and is constant throughout the condenser. The partial pressure of the steam or water vapor is determined by the temperature existing, the lower the temperature, the lower the steam pressure. The lower the pressure and the temperature of the vapor, the higher must be the pressure of the air, since the total pressure remains constant. Assume then that with a 28 in. vacuum, the temperature of the air pump suction is 90 deg. The pressure of the steam in the mixture being determined by that temperature, we obtain from steam tables that the partial pressure of the steam equals 1.417 inches of mercury. The remaining pressure 2 — 1.417 = 0.583 in., is the partial pressure of the air. From this pressure and the temperature of 90 deg. the volume of each pound of air is determined as follows:

$$12.387 \times \frac{29.92}{0.583} \times \frac{460 + 90}{460 + 32} = 710 \text{ cu. ft.}$$

where 12.387 is the volume of a pound of air at 32 deg. Fahr. and a pressure of 29.92 inches of mercury or atmospheric pressure.

Now if the temperature of the air pump suction be 70 deg. Fahr., then the pressure of the steam vapor in the mixture will be 0.739 inches of mercury, as obtained from steam tables and, therefore, the air pressure must be 2 —.739 = 1.261 inches of mercury. Thus it is seen by reducing the temperature of the air pump suction 20 deg. the pressure of the air has been more than doubled. This results in a pound of air being:

$$12.387 \times \frac{29.92}{1.261} \times \frac{469 + 70}{460 + 32} = 320 \text{ cu. ft.}$$

The curves in Fig. 19 are figured on a similar basis and show the volume of an air-steam mixture containing one pound

of air, for different vacuums and for different temperatures of air pump suction.

Cold air pump suction is especially necessary in jet condensers because with that type more air must be removed than with the surface condenser. It is well known that water contains in solution a large amount of air. Under reduced pressure in the condenser, this is liberated and unless removed by the pump, will greatly reduce the vacuum maintained. Experiment has shown that the total amount of air in a jet condenser is contributed from three sources about as shown in Fig. 18.

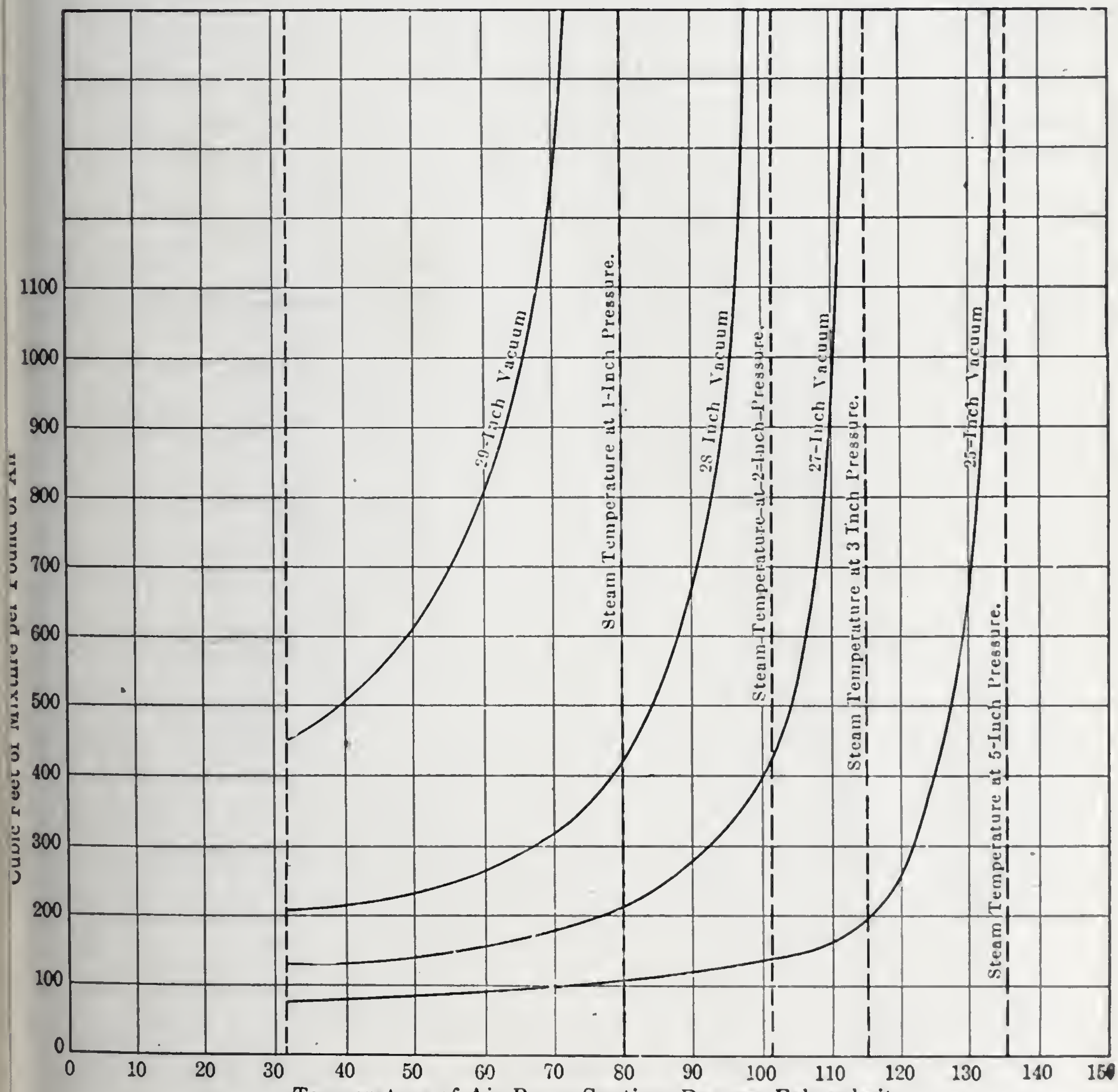

Fig. 19. Volumes of Air Steam Mixtures per Pound of Air.

Air can also be introduced with the circulating water, in a suspended or globular state, where the water supplied to the condenser has been allowed to spray or become similarly broken up, so as to be intimately mixed with the atmosphere. With still water, however, the amount of air in each cubic foot of water may in general be said to vary about as shown in Fig. 20, which gives the weight of air per cubic foot of water for atmospheric pressure (29.92 inches of mercury) and temperatures from 32 to 85 deg. When water enters a condenser, the amount of air liberated from it will depend upon the pressure of the air above the surface of the water. In a condenser, the total pressure is very small and the partial pressure of the air itself is only a part of that total pressure, so that it is quite accurate to calculate that all the air dissolved in water is liberated when that water enters a jet condenser.

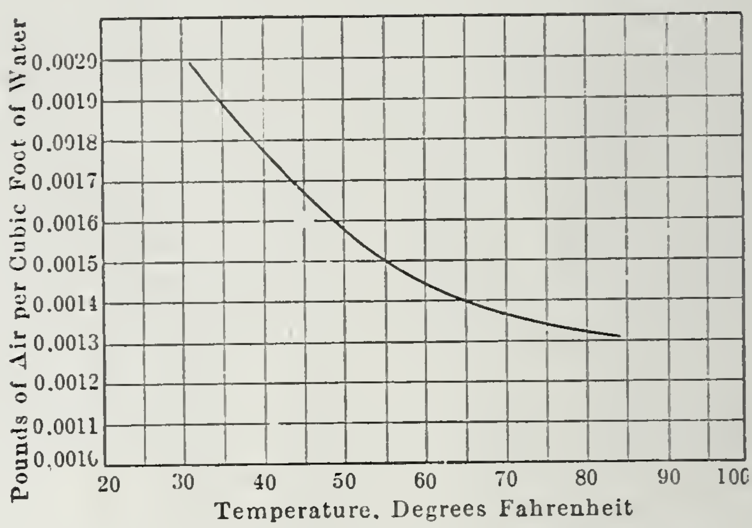

Fig. 20. Solubility of Air in Water.

While the amount of air by weight dissolved in each cubic foot of water seems to be very small, the actual volume of air becomes very large because of the low pressure existing. For instance, assume the amount of cooling water as 8000 gal. per min., or roughly, 1000 cu. ft. If the temperature of the water were about 55 deg. the amount of air brought into the condenser in solution with the water would be $1000 \times 0.0015 = 1.5$ lb. If the vacuum in the condenser were 28 in. then the volume of a pound of air at 55 deg. air pump suction temperature and 28 in. vacuum is obtained from Fig. 19 as 250 cu. ft. The air pump capacity necessary, therefore, to remove the air brought in by the circulating water would be $1.5 \times 250 = 375$ cu. ft. per min.

The Author: I quite agree with Mr. Owitz that the higher price of the larger air pump is a good reason for the great number of small air pumps in existence. Purchasing agents have to earn their salary. There would be less complaint on the part of engineers, if purchasing agents had strict instructions to always throw out the bid with the smallest air pump, no matter how low or "attractive" the price might be. Incidentally, there would be fewer law suits, if all lowest bids were thrown out.

With regard to the engineering part of Mr. Owitz' discussion, I am afraid that it does not tell us much. The "test" shown in his table means nothing. We do not know the rate of flow of water through the condenser; neither do we know the rate of flow of air into the condenser. I can make most any condenser give equally good results, if I cut down water and steam flow and prevent air leakage.

This condenser, the interior arrangement of which is shown in Fig. 17, is of the counter current type. As mentioned in my paper, the pressure at the top and at the bottom are determined by different considerations. With a large, fast running air pump, small water flow and little air leakage, steam must break into the top of the condenser and spoil the efficiency of the air pump. With all due respect for Mr. Owitz, it appears to me that the factory have not told him everything and that he would find out several interesting facts in experimenting with condensers. Mr. Owitz as well as other engineers interested in condensers are cordially invited to come out to the Carnegie Institute of Technology and make use of our equipment.

Going back to Mr. Nibecker's discussion, I wish to answer his question concerning the type of air pump used by me. The characteristics shown in Fig. 4 belong to a pump without flashports. In my tests at the Carnegie Institute of Technology I used a pump with flashports; but since it did not pull enough vacuum to bring out the laws of air influence, I connected it in series with a single acting oil sealed reciprocating pump.

TEST OF LARGE REVERSING ENGINE AND ROLLING MILL

By Karl Nibecker*

The object of this paper is to describe the methods used in testing a 46 in. and 76 in. by 60 in. twin tandem compound reversing engine driving a 44 in. reversing blooming mill when rolling 20 in. by 22 in. ingots. It is also proposed to give an outline of the methods used and assumptions made in arriving at the power and steam consumptions as determined for this mill. Results of steam consumption tests of other sizes of ingots will also be exhibited.

The engine is operated condensing using steam at 140 lb. gauge pressure at the throttle valve and exhausting into a 28 in. vacuum. The condenser used is a 120 in. steam pipe supported barometric condenser, the air pump being 14 in. and 36 in. by 24 in. reciprocating type, with automatic inlet and outlet valves.

In Fig. 1 is shown the engine and air pump, the condenser being located directly outside of the building. The steam separator is shown directly back of the engine. The low pressure cylinders are placed adjacent to the beds on either side. The engine is direct connected to the mill but separated from it by means of a brick wall. The mill pinions and couplings being shown in the figure.

Figure 2 represents a diagrammatic arrangement of one side of the engine and valve gear, showing the method of control. This control is rather novel, and we believe quite new in this country, although it has been used in Europe with varying details of arrangement. It will be noticed that the mechanism is operated by a single lever, as shown at *A*, Fig. 2. This lever, which is located in the pulpit, operates the relay valve which controls the steam to the reversing cylinder, operating both

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*Steam Engineer, Youngstown Sheet & Tube Co., Youngstown, Ohio.

the reversing links and the throttle. The reversing piston is cushioned by means of a suitable oil cylinder connected to the reversing gear cross head.

The three positions of the main reversing lever and cross head are shown by points *1*, *2*, and *3*. The pressure of the steam through the throttle valve and the point of cut-off with which the engine works are thus both determined by the motion of this cross head. It is therefore essential that the engine when operating under light loads must work with a combination of throttle and cut-off control.

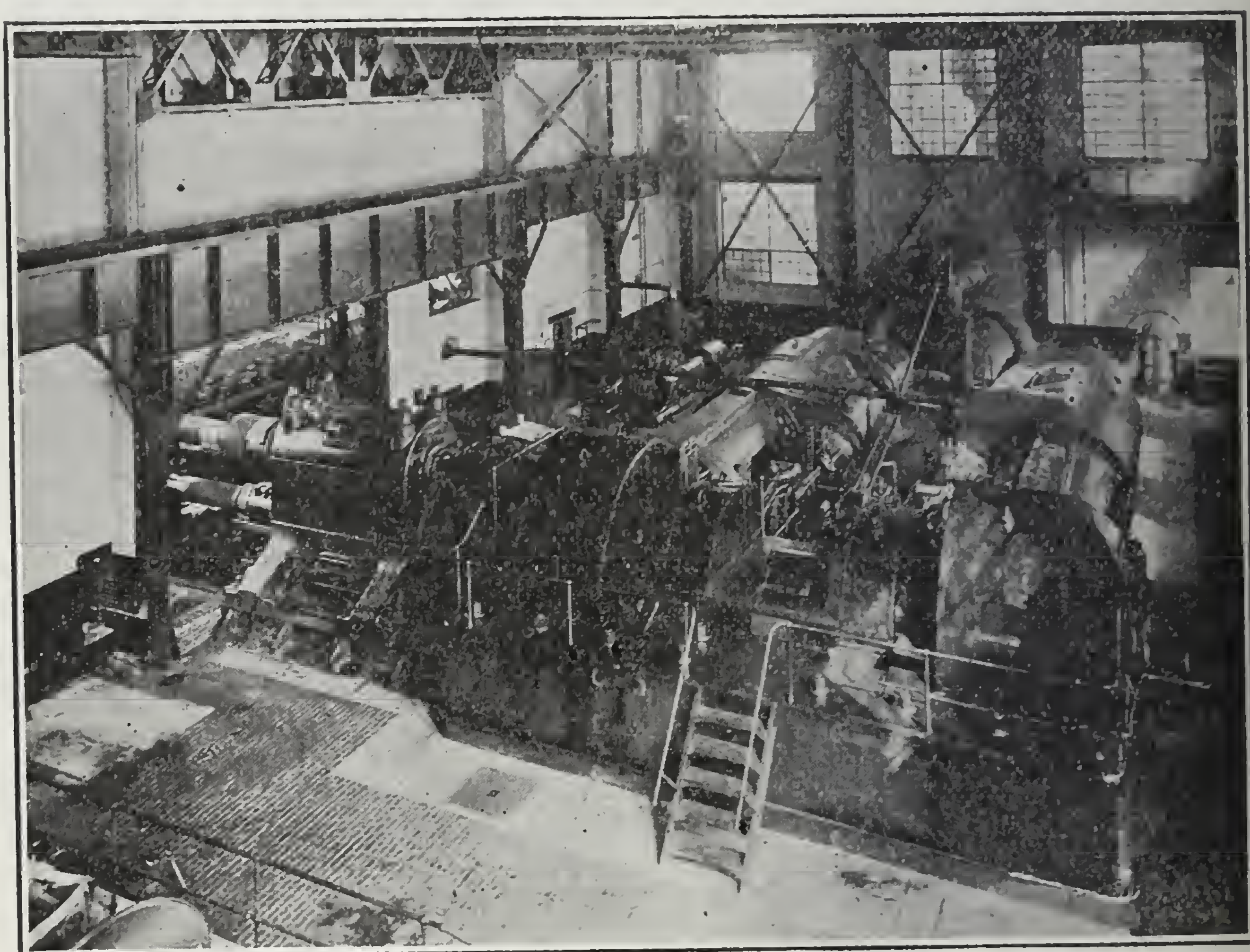


Fig. 1. General Arrangement of Mill Drive.

The throttle valve is arranged so that its opening does not occur with the beginning of the movement of the reversing lever from its center position. A certain amount of lap is provided so that the valve gear is moved an appreciable amount from its neutral position before the steam valve is opened. When the throttle valve opens, steam is admitted through auxiliary ports in the main piston valve. By this combination of lap on the throttle valve and auxiliary ports in the main

valves of the engine, it is possible to start the engine at any position of the cranks. The auxiliary ports are in operation during the regular running of the engine, but are too small to affect the economy of the engine or the shape of the indicator cards.

The high pressure and low pressure steam valves of the engine, which are of the piston type, are arranged in a straight line, so that both can be driven from one rocker, this construction greatly simplifying the valve gear.

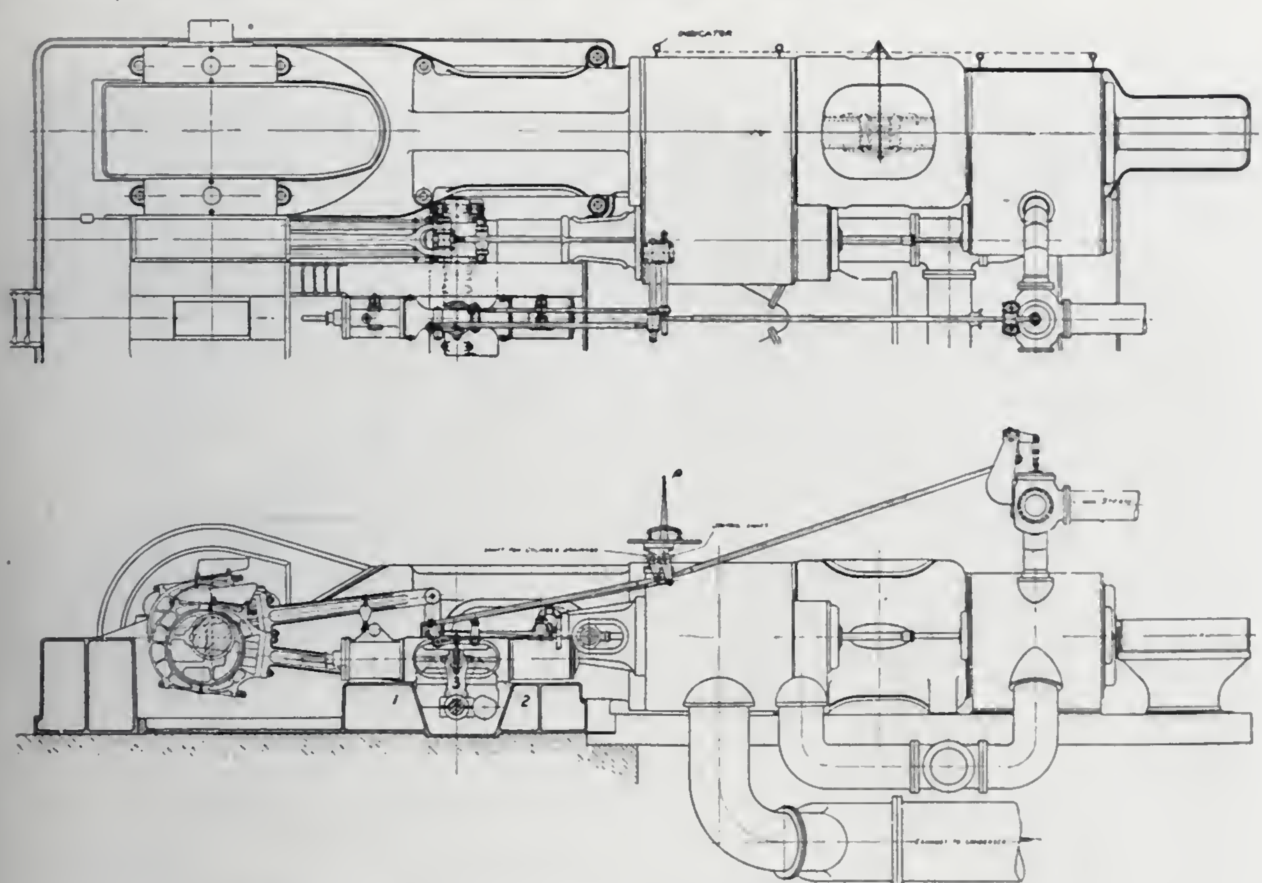


Fig. 2. Diagram of Control Mechanism.

With the arrangement of reversing cylinder, control of the throttle valve, and links as above described, it will be seen that the ordinary "plugging" effect is greatly reduced and also it is impossible for the operator to run the engine with full cut-off and control the speed by means of simply throttling the steam. The saving due to the large amount of steam which is consumed in plugging the engine and also the losses which occur due to running with throttled steam and late cut off are greatly reduced by this system.

Figure 3 illustrates the engine looking from the cylinders towards the cranks. The steam throttle valve is shown in the foreground and is controlled by means of rod shown, which is

operated by reversing piston. The control shaft to the pulpit is indicated passing across the left hand engine and through the building. This shaft is seen in Fig. 4, driving the smaller of the two rods leading to the reversing mechanism. The larger rod in Fig. 4 running from the reversing mechanism is the throttle valve control. The links are operated by means of reversing cylinder through suitable connections under the floor plates. The auxiliary steam valve is shown at the distant end of the reversing cylinder in the center of this figure, the oil cushioning cylinder being in the foreground.

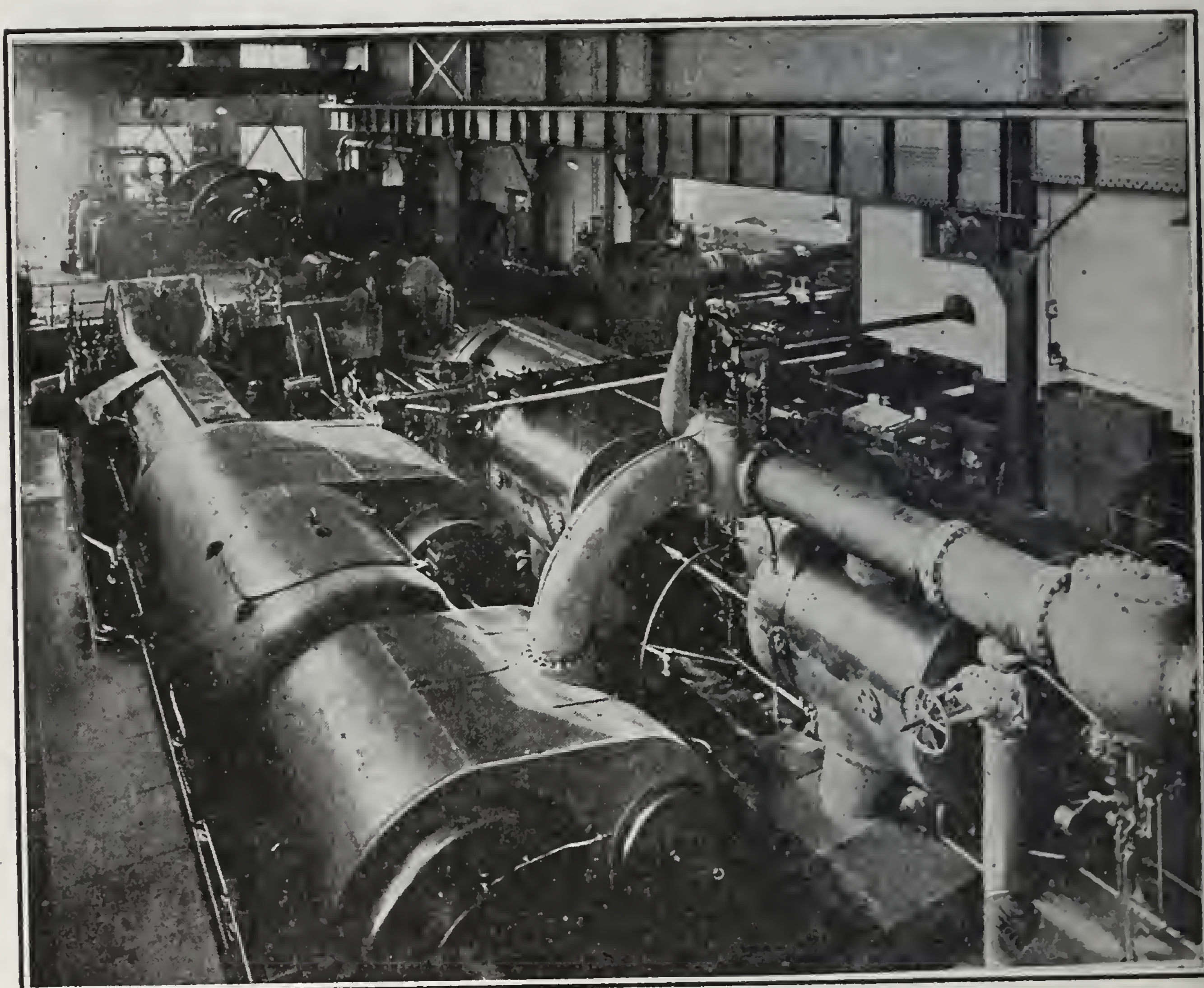


Fig. 3. Steam End of Engine.

Figure 5 illustrates the pulpit and back end of the mill. The size of the ingots delivered to the mill were measured at this point as the ingots were delivered by ingot buggy.

Figure 6 is a general view of the mill at the front, showing the shears at which the final length of the bloom was measured.

Continuous indicators were applied to each end of the four cylinders, the arrangement of one side being as shown in Fig.

7. These four indicators were equipped with electro magnets for starting and stopping the paper and also for applying the pencil to the drums. The other four indicators were manually started and stopped at a given signal operated by the same key which actuated the starting magnets on the electrically operated indicators. The indicators were also supplied with electro magnets for locating various events. On five indicators the dead centers of the engine were marked by means of suitable magnets.

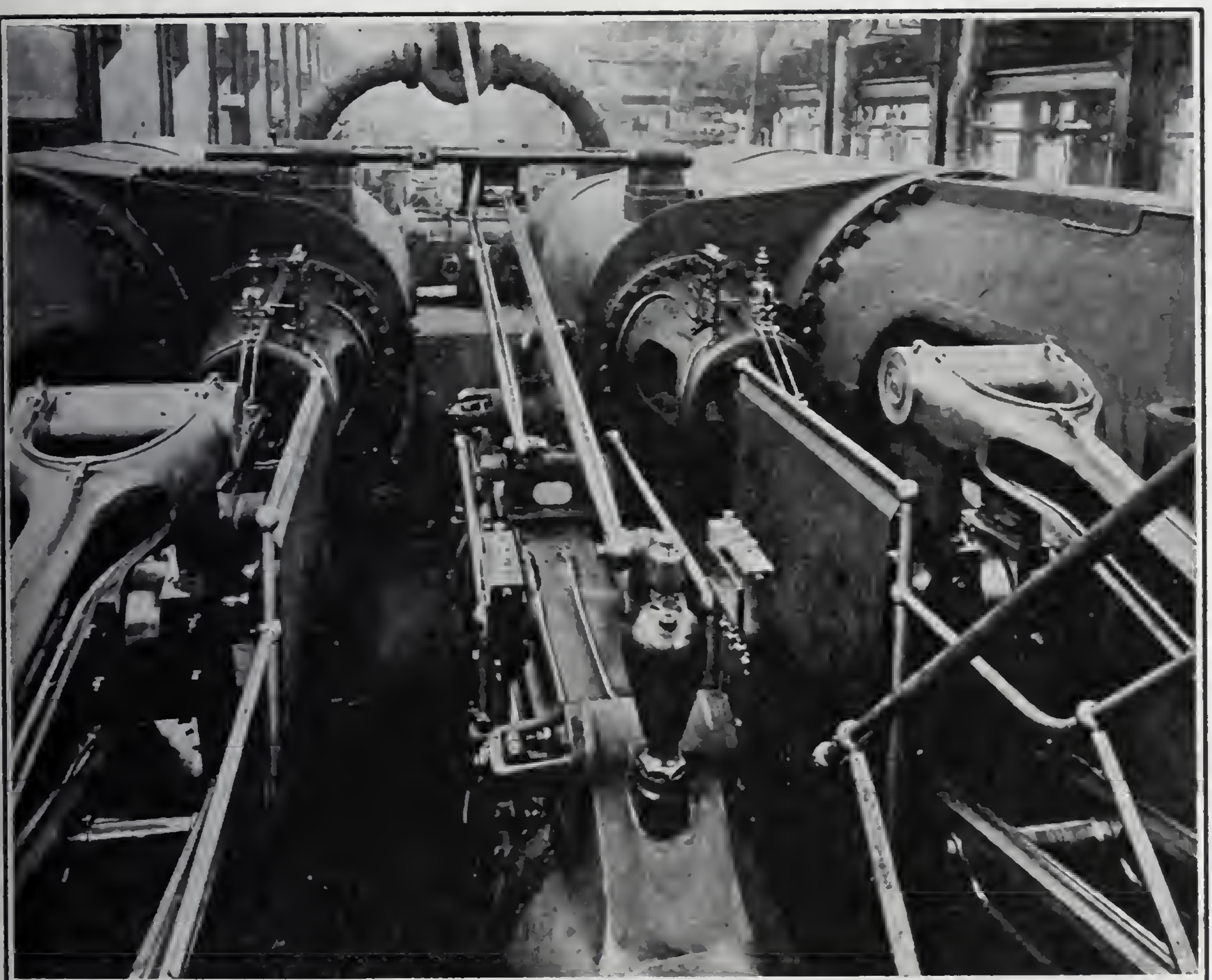


Fig. 4. Valve Gear of Engine.

The point of opening and closing of the steam throttle valve was recorded by means of one magnet. The position of the cross head of the reversing cylinder was determined by a magnet on one of the indicators. This magnet indicated when the piston of the reversing cylinder was in its dead center position and when it was off the dead center position. The dead center position of this piston represents the point where the steam

throttle valve was closed and the links were in their neutral position.

A magnet was provided on one indicator for recording ½ second intervals. This magnet was operated by means of a clock which caused the magnet to be depressed each half second, thus giving a record of time.

Figure 8 shows the wiring diagram of electric connections for indicator magnets. Storage batteries were used for furnishing the current for operating these instruments. The figure is self-explanatory.

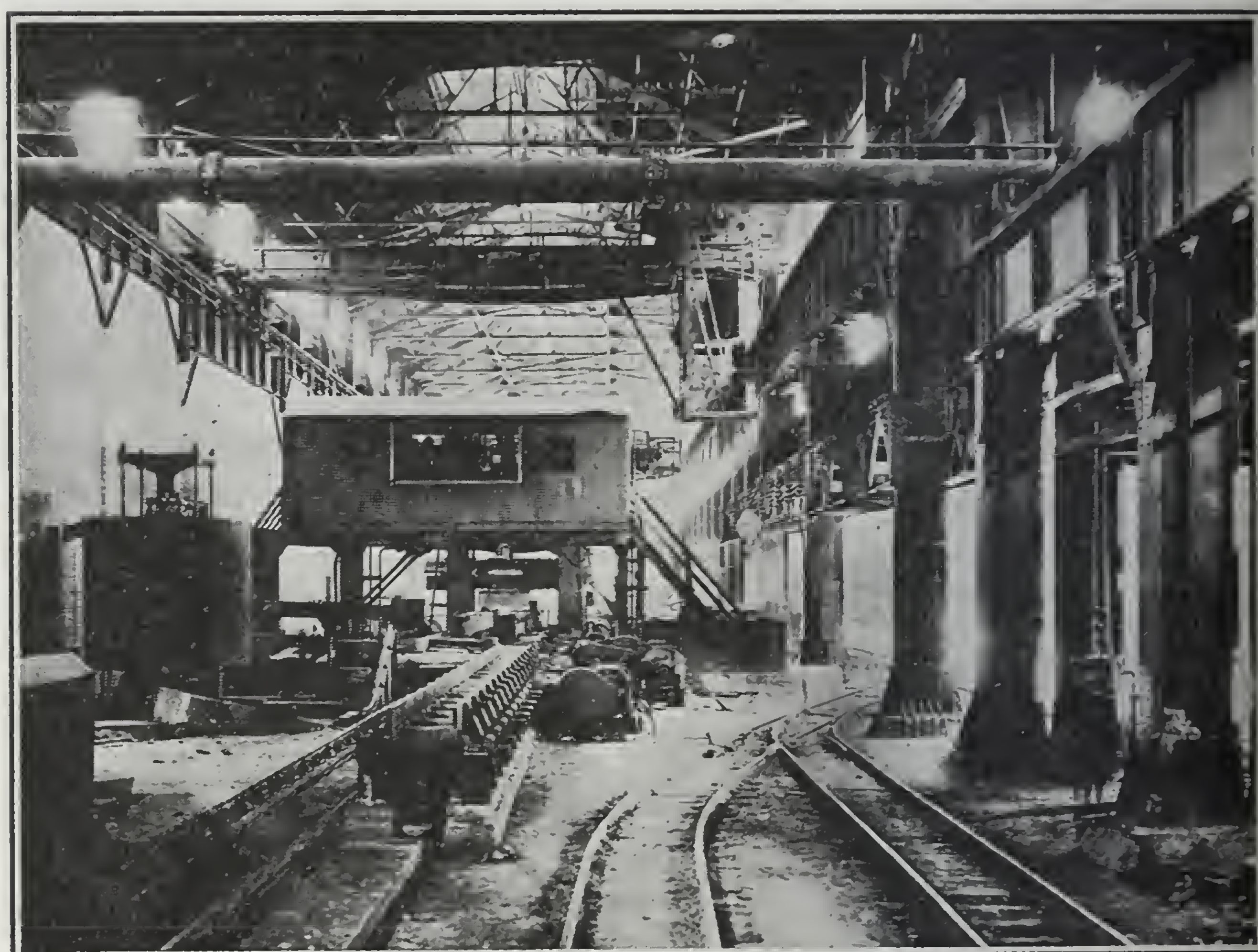


Fig. 5. View of Pulpit and Rear End of Mill.

The temperature of the piece was determined by means of a Wanner Optical pyrometer. Observations of temperature were taken as the piece entered the first, third, fifth, etc. passes,—or on every second pass. These temperatures were read at the back end of the mill as the piece was being manipulated. Lengths were also determined at this point in order to check the areas as determined by other means. The finished length of the bloom and its cross section were carefully determined before shearing the finished piece.

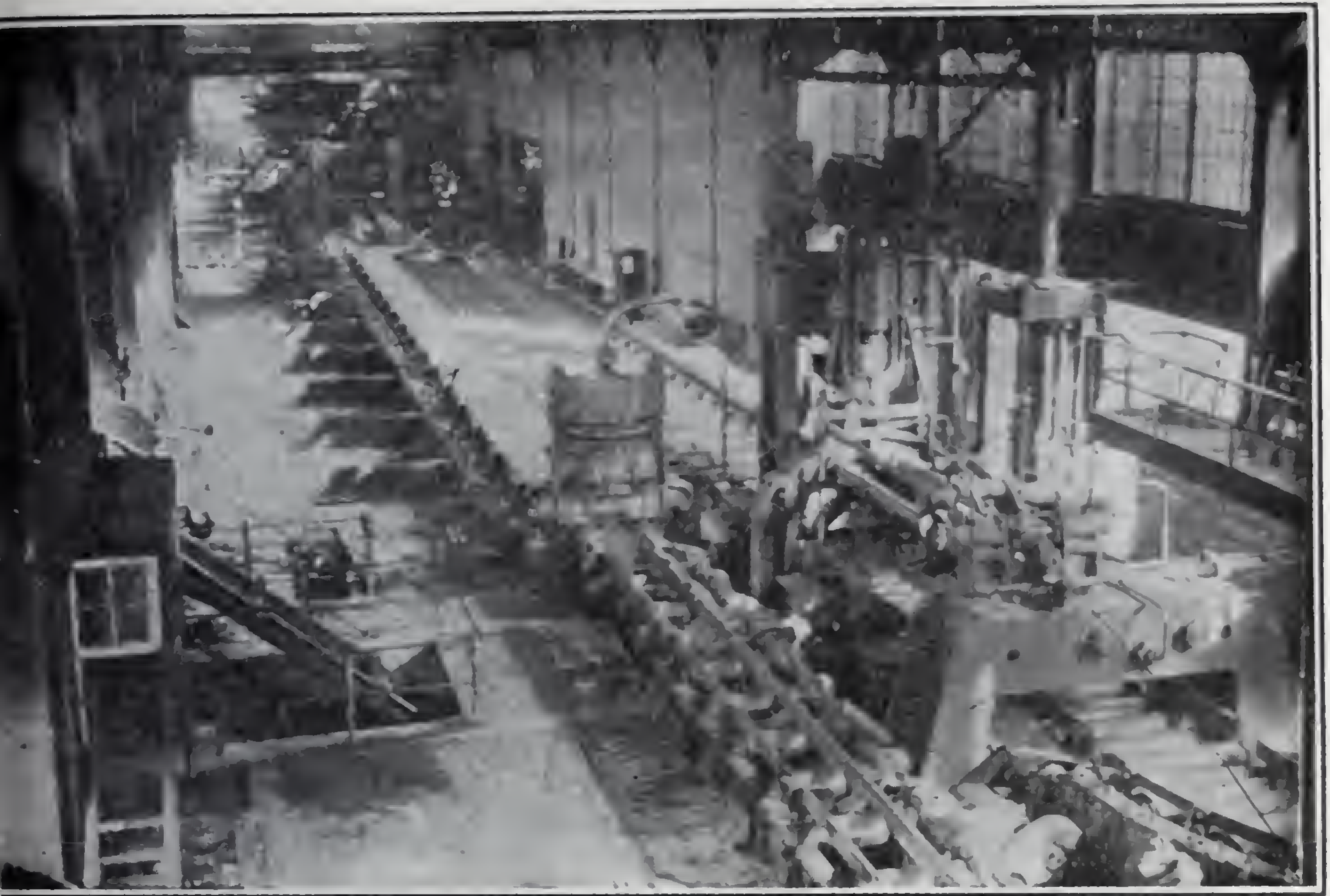


Fig. 6. General Arrangement of Mill.

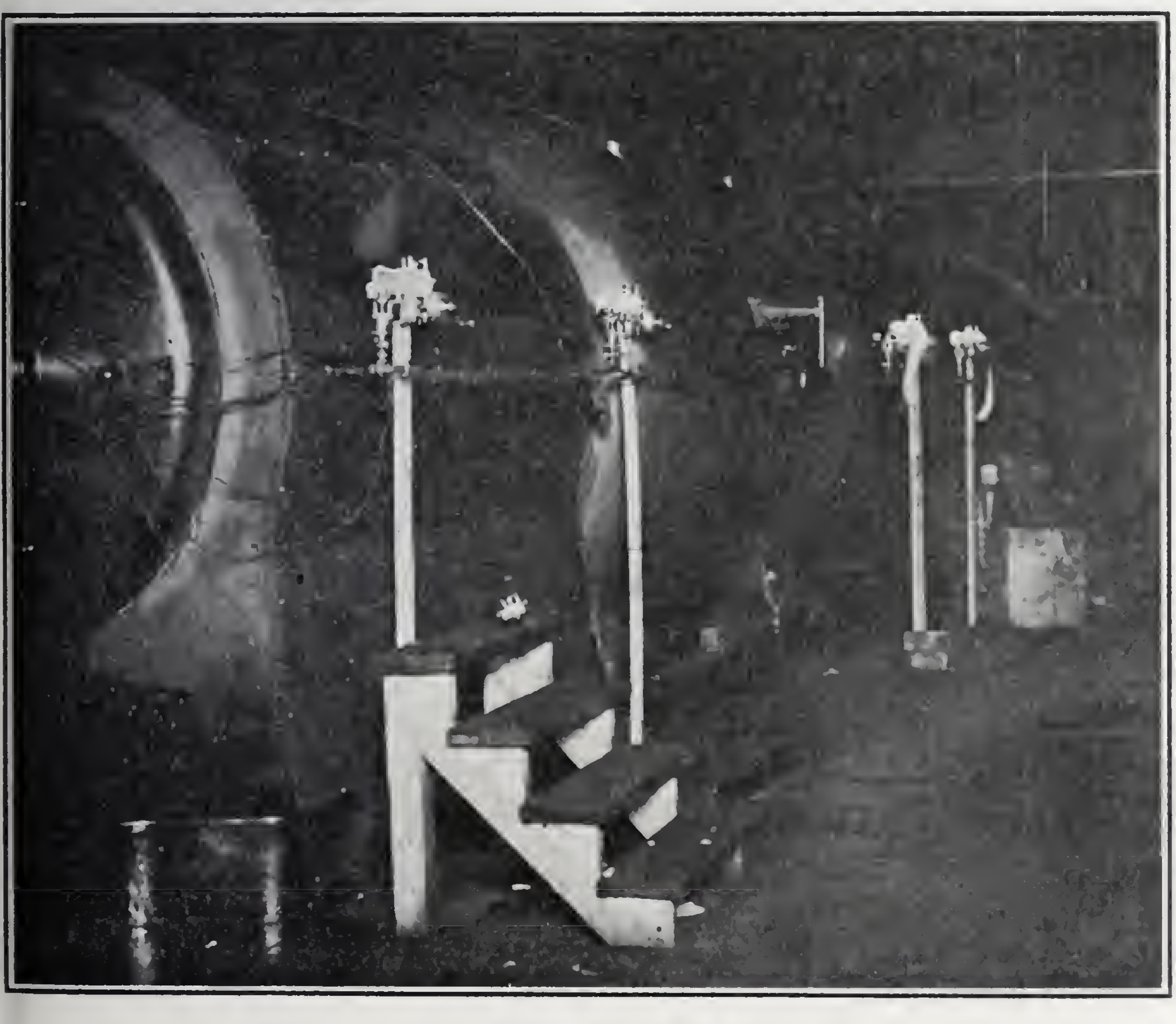


Fig. 7. Arrangement of Indicators.

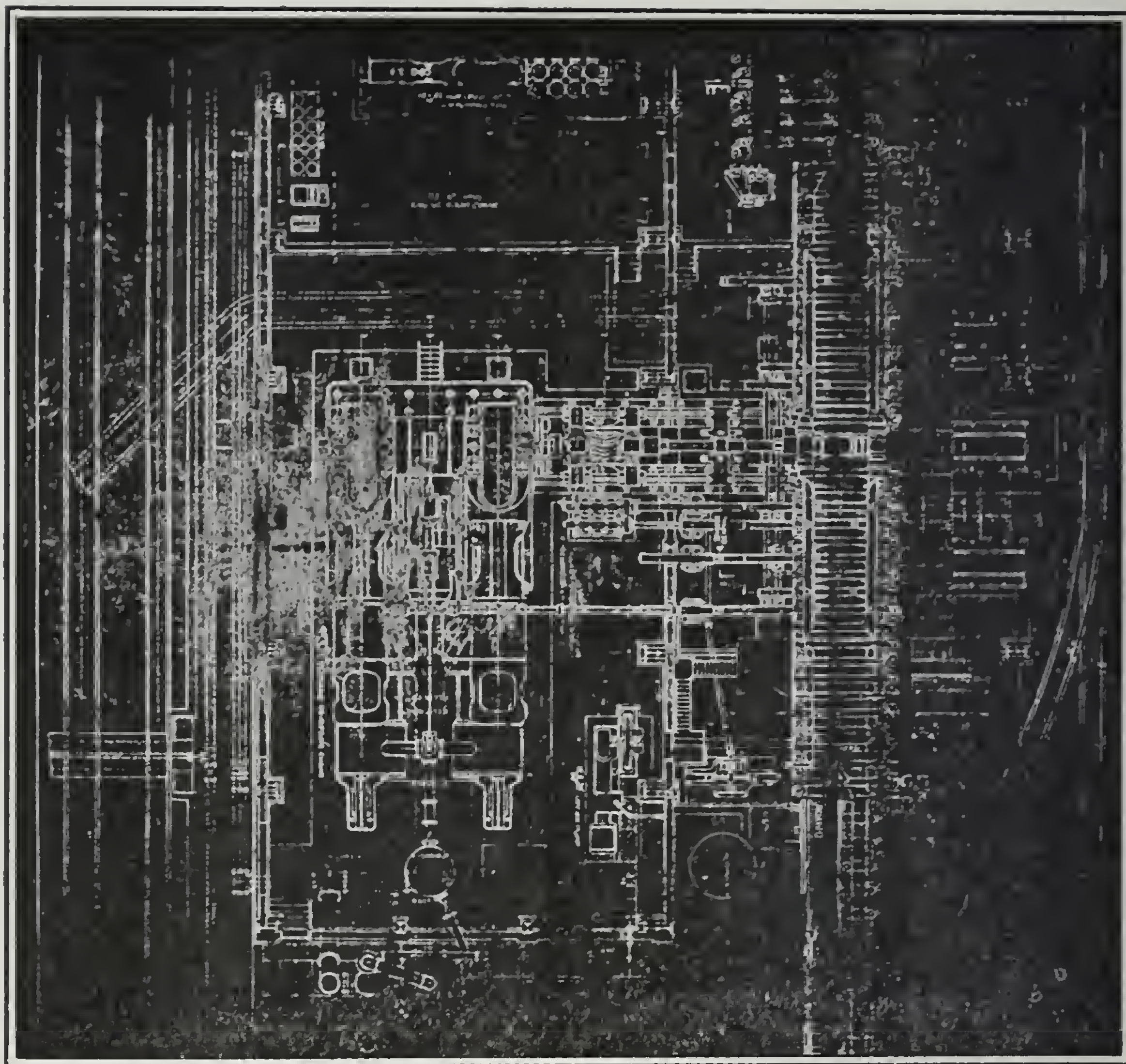
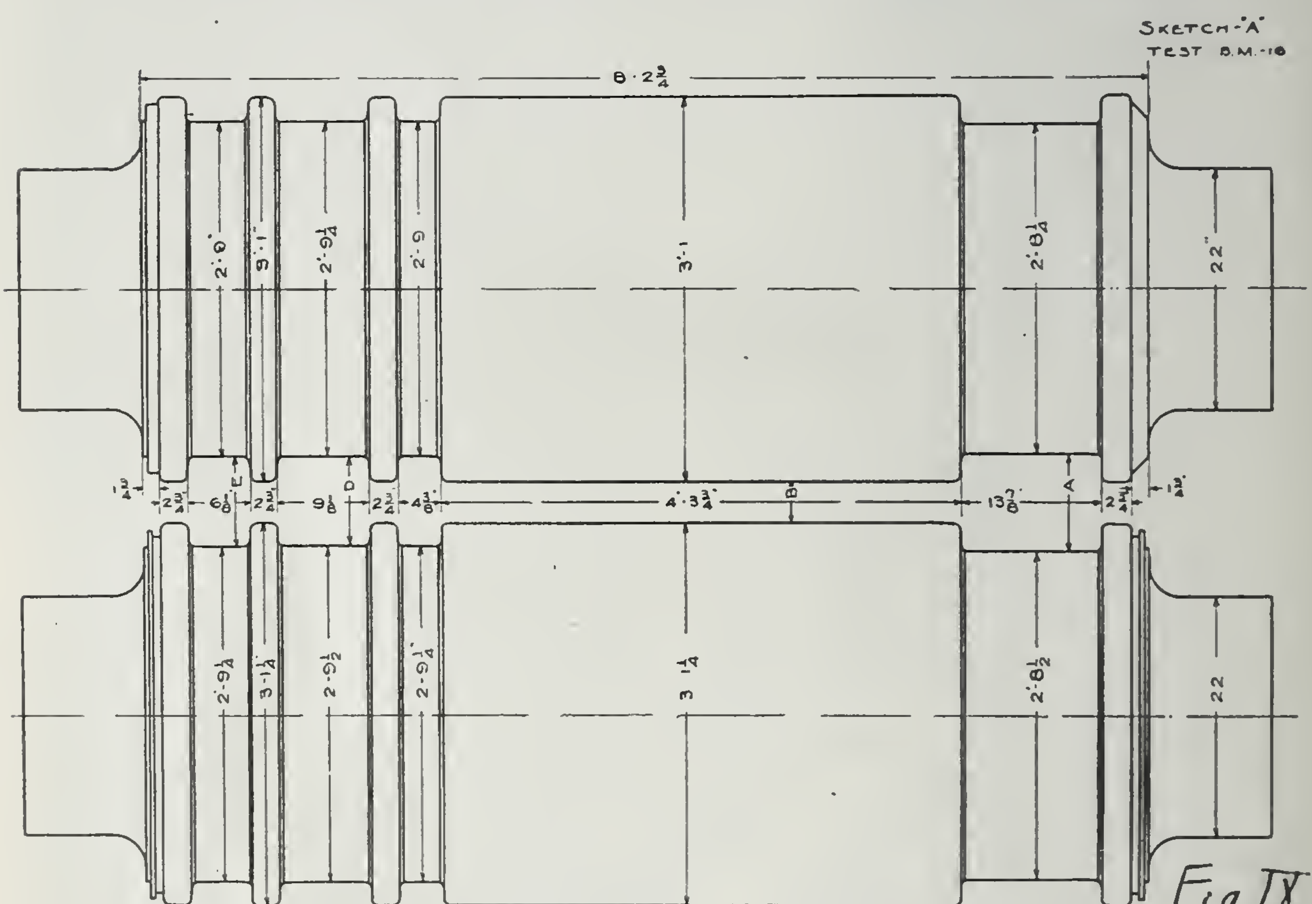


Fig. 8. Wiring Diagram showing Electrical Connections.



Gouge Wheel Reading	Observation No	A	B	D	E
22 1/4	1	22 15/16"	18 1/2"	21 15/16"	22 1/2"
16 9/16	2	17 5/16"	12 7/8"	16 1/4"	16 13/16"
7 13/16	3	8 5/8"	4"	7 9/16"	8 1/8"
7	4	7 15/16	3 1/4"	6 3/4"	7 1/4"

Y. S. & T. Co
#2 BM Rolls

12-13-13 EJP

Fg. 9. Roll Dimensions.

Three observers were stationed in the pulpit. One depressed a key operating the electric circuit controlling the pass magnet. This key was depressed as the piece entered the rolls and held in this position until the piece left the rolls. A second operator kept a record of the groove of the roll that was being used and the third read the gauge wheel on each pass. After the test the gauge wheel readings were calibrated as shown by Fig. 9. From this calibration and the records kept in the pulpit, it was possible to determine the setting of the rolls for each pass.

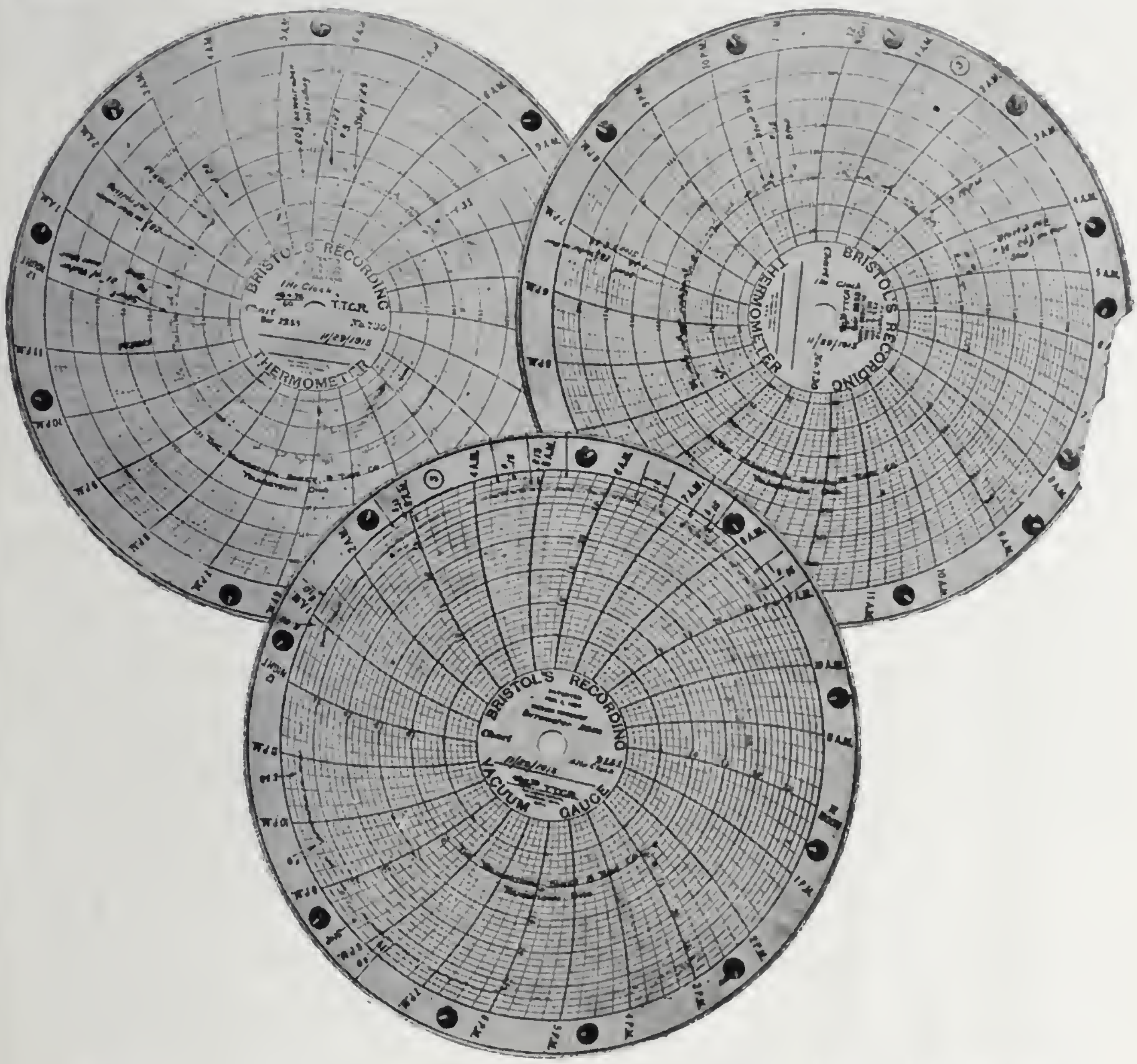


Fig. 10. Temperature and Vacuum Charts from Condenser.

A three point recording thermometer was installed on the condenser and also recording vacuum gauge which was carefully calibrated by means of mercury column. The thermometer was equipped with a clock producing one revolution of the chart per hour and the vacuum gauge one revolution in four

hours. The three pointers on the thermometer indicate the temperature of the exhaust steam, temperature of tail water from condenser and temperature of inlet water to the condenser.

Photographs of the temperature and vacuum charts are shown in Fig. 10. The amount of water passing through the condenser was estimated by means of a 22 in. weir placed in the over flow of the hot well from the condenser. The instant when the piece entered the rolls and left the rolls finished was carefully recorded on the chart by an observer at a given signal operated by the pass key. These points will be seen on charts Fig. 10. Suitable records of the weight and analysis of each ingot were also kept.

Figure 11 exhibits a portion of all indicator cards taken from this engine. The reversals on each card are clearly marked, and numbered for convenience in co-relating the several records. On the high pressure, head end, right side cards are shown the dead center markings produced by the magnet. The seconds magnet was also on this indicator but the clock did not operate satisfactorily when these cards were taken and hence there are no speed records available. A satisfactory clock has since been constructed and in tests subsequent to this one satisfactory time records are available. On the high pressure, crank end, right side cards are shown the dead center markings and also the point where the throttle valve opened and closed. On low pressure, head end, right side cards is shown the dead center markings and the point where the reversing jack moved from its dead center position. On low pressure, crank end, right side cards is shown dead center markings and the points where the piece entered and left the rolls. On low pressure, head end, left side cards the bottom line was used for indicating dead centers, but during the portion of card where this photograph was taken this magnet was not in operation.

CALCULATIONS

In working up indicator cards each card of each set is numbered and the reversals located as nearly as is possible by means of dead center markings. This enables all sets to be actually co-related. The cards are then planimetered and the

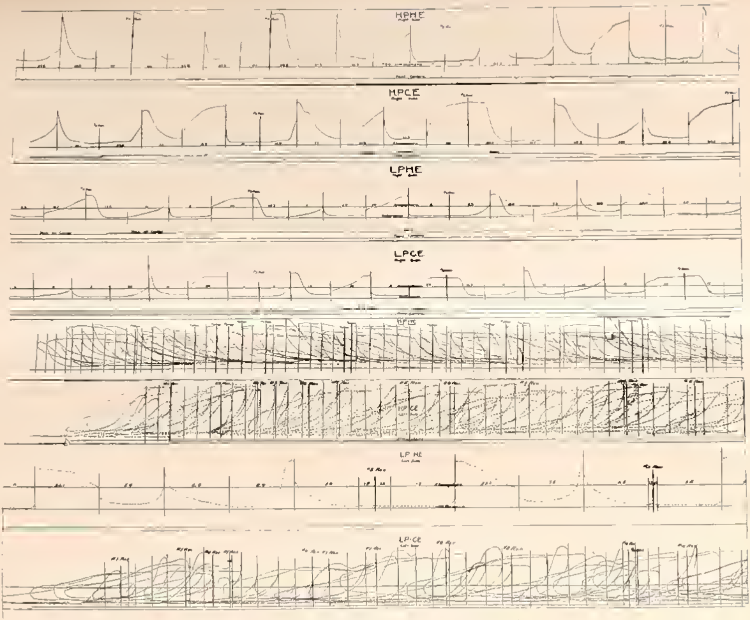


Fig. 11. Indicator Cards from Test No. 16.

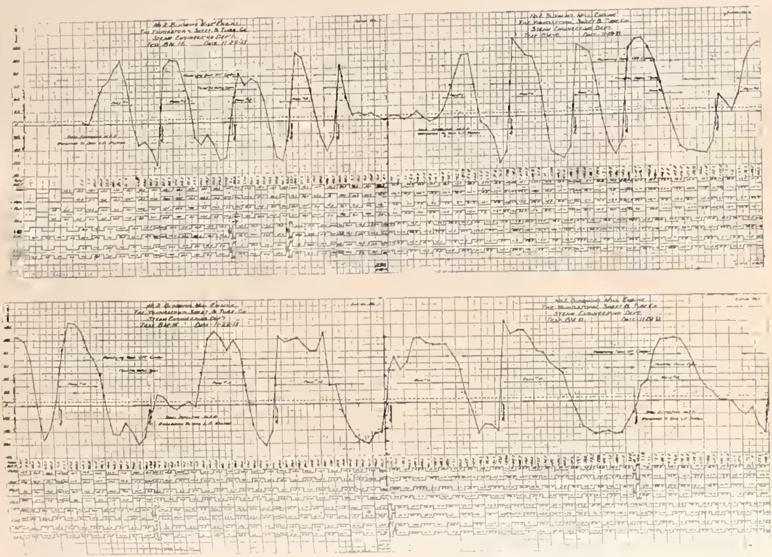


Fig 12. M. E. P. Diagram from Test No. 16.

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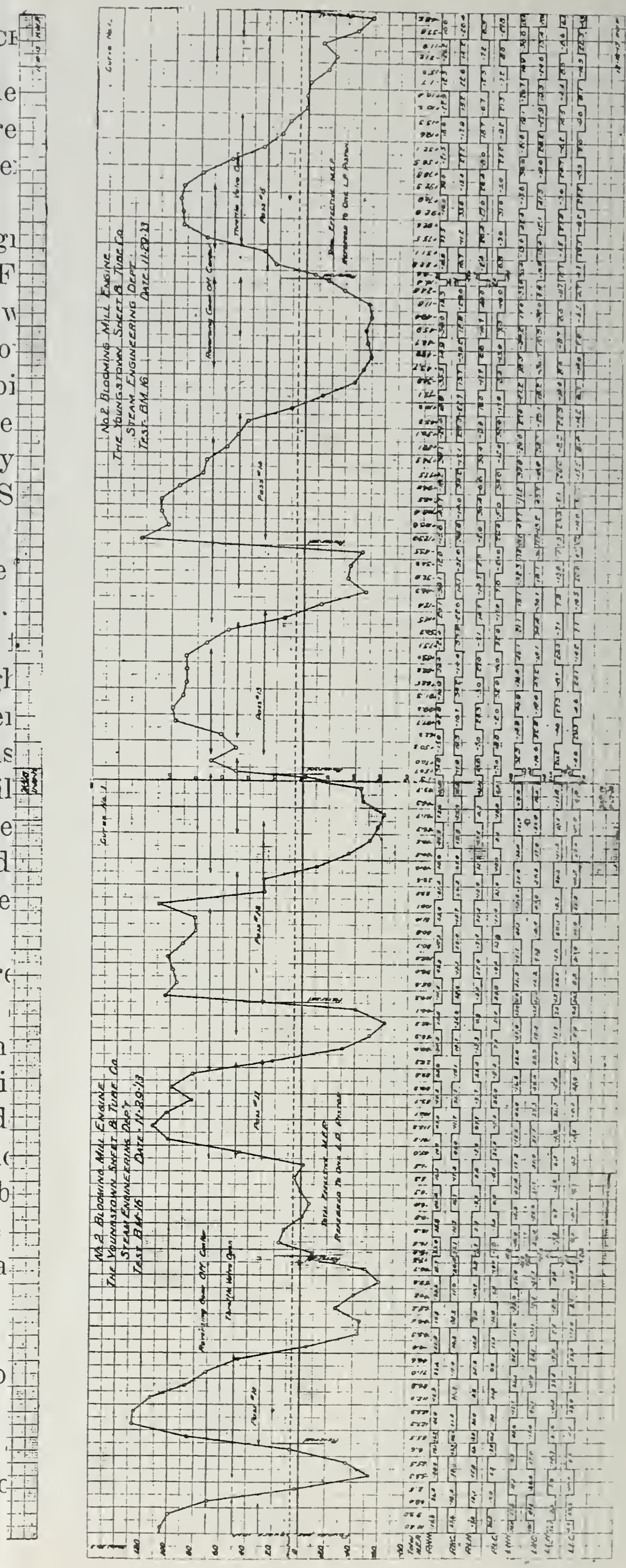

Fig. 12. M. E. P. Diagram from Test No., 16.

mean effective pressures determined for each stroke. These are plotted as shown in Fig. 12.

A more detailed description of the method of handling the cards will be found in volume 29 number 8 of the Proceedings of this Society in the paper by Messrs. Siebert and Fitzgerald. As the methods of plotting the cards and, in general, the methods of calculation as outlined by Messrs. Siebert and Fitzgerald have been followed in this test, a detailed description of the methods will therefore not be given; a general outline only of this work will be given and your attention will be called to such points at which their work has been deviated from.

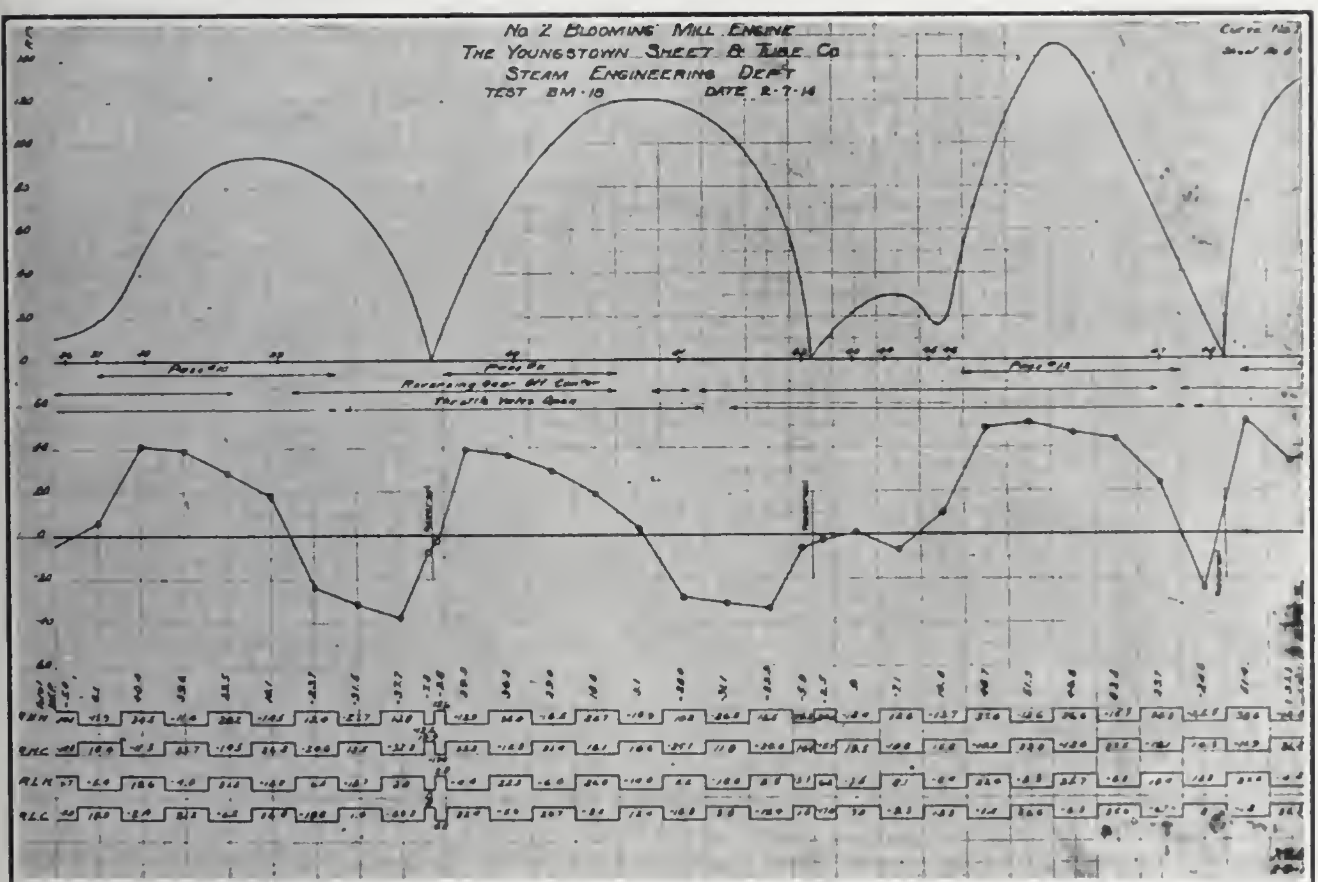

Fig. 13. M. E. P. and Speed Curve from Test No. 16.

The mean effective pressure of all cards referred to one low pressure piston are plotted as shown in Fig. 12 at the bottom, the scheme of plotting being as described by Messrs. Siebert and Fitzgerald. The mean effective pressure curve is then plotted as the algebraic sum of these curves. The position of the reversing gear and throttle valve are indicated and also the time when the piece is under the rolls. If seconds or half seconds are available, they are also plotted on this curve and from these a speed curve is determined. This portion of the work has

been dropped from this test as the record was not available. Fig. 13 however, will show such a curve from another test from which the speed curve was plotted.

Table No. 1. Distribution of Work in Foot Pounds from M. E. P. Curve from Test No. 16.

TEST-BM-16 11-29-13				Work done as figured from areas for passes as shown on Curve No. 1—Sheets Nos. B-119—B-122			TABLE 1
Area under Curve No. 1 (sq. in.) 1" Vertical = 40 lb. (Spring) 1" Horizontal = 10 ft. (2 strokes) 1 sq. in. = 40×10 = 400 ft. lb.				Work in Ft. lb. = Area under Curve No. 1 (sq. in.) × Area of L. P. piston (4335.4 sq. in.) × 400			Net Work —Friction Work
Passes	+ sq. in.	— sq. in.	Friction sq. in.	+ Work	— Work	Friction Work	Rolling Work
1	2.61		.26	4525000		451000	
		.92	.17		1597000		2477000
2	2.28		.19	3953000		330000	
		1.25	.23		2166000		1457000
3	1.91		.22	3313000		382000	
		.83	.13		1440000		1491000
4	1.74		.15	3020000		262000	
		.53	.11		920000		1838000
Running Idle	.92			1597000			
	.03			52000			
	.06			104000			
		.02	.54		34650	936450	
5	2.13		.24	3694000		416000	
		.95	.17		1648000		2411900
6	2.75		.21	4770000		364000	
		1.32	.16		2290000		2116000
7	2.13		.17	3694000		295000	
		.78	.13		1353000		2,046,000
8	3.45		.25	5980000		434000	
		2.25	.28		3900000		1646000
9	3.77		.39	6540000		676000	
		.55	.11		954000		4910000
10	4.14		.34	7183000		590000	
		1.8	.29		3120000		3473000
Running Idle	.16			277500			
		.03			52000		
	.02		.15	34650		260150	
11	3.98		.32	6900000		556000	
		1.03	.14		1788000		4556000
12	5.00		.37	8670000		642000	
		1.86	.27		3225000		4803000
13	5.61		.46	9740000		799000	
		.93	.18		1614000		7327000
14	5.23		.42	9070000		729000	
		2.33	.38		4040000		4301000
15	4.45		.46	7720000		799000	
		.70	.27		1214000		5707000
Total				90837150	31355650	8,921,600	50559900

$$\text{Acceleration (Work)} = \frac{31355650}{90837150} = 34.5\%$$

$$\text{Friction Work} = \frac{8921600}{90837150} = 9.8\%$$

$$\text{Rolling Work} = \frac{50559900}{90837150} = 55.7\%$$

The mean effective pressure as given in Fig. 12 is then planimetered. The area above the zero line being considered positive and the area below the zero line being considered negative. These areas are given in Table No. 1. The area of the mean effective pressure curve representing friction is as shown in Table 1, and is determined by the area between the friction mean effective pressure line and the zero line, Fig. 12.

It is assumed that the mean effective pressure required in friction is constant and this value was separately determined by running the engine at constant speed and determining the mean effective pressure for the average speed of the mill. This value is shown by dotted lines, Fig. 12, having a value of 6 lb. per sq. in. referred to on low pressure piston.

From the areas determined, the work corresponding to these areas is calculated in foot pounds by multiplying the area under the curve by the area of the low pressure piston by the product of the scales of the curve. The amounts of work thus calculated are as given in Table No. 1. The rolling work, i. e., the work actually consumed in deforming the metal, is determined by subtracting the minus work in each pass from the positive work and then subtracting the friction work. It is assumed that the work consumed in stopping the rotating and reciprocating parts is the same as that consumed in accelerating them. It is upon this assumption that we subtract the minus work from the plus work in order to obtain the rolling work. Considering the plus work as the total available power developed by the mill, we calculate the percent of this work consumed in acceleration, i. e. in starting the moving parts, the friction work and the rolling work, by simple division, as shown in Table No. 1.

In Table No. 2 is recorded the grooves of the rolls, which were used, as shown in Fig. 9. The width in inches for each pass is calculated from the formula for spread which is:

$$\textit{Spread} = \frac{\textit{Arc of contact} \times \textit{draft} \times \textit{sine (angle of contact)}}{\textit{Height of bloom after pass}}$$

The height in inches is determined from the reading of the gauge in the pulpit corrected from calibration. The difference in heights determines the draft in inches. The length is cal-

Table No. 2. Summary of Results from Test No. 16.

Pass No.	Pass See Sketch "A"	Width Inches	Height Inches	Draft Inches	Area Sq. In.	Length Inches	Elong- ation	Displace- ment Cu. In.	Reduc- tion %	1000 Foot Pounds Used in Rolling	1000 Ft. Lbs. Used in Rolling Per Cu. In. Displacement	Total Steam Per Pass	Total Steam	Steam Per Ton	Ingot Temp. °F
Ingot		18.50	20.50		379.0	40.5									
1	B	18.67	17.87	2.63	333.5	45.8	1.14	1840	11.54	2477.	1.343	28.46	37.0	19.1	
2	B	18.80	16.37	1.50	307.8	49.8	1.23	3020	8.51	1457.	1.232	40.01	88.9	46.0	2165
3	B	18.93	13.87	2.50	262.5	58.4	1.44	5280	14.70	1491.	.661	36.02	136.0	70.4	2228
4	B	19.06	11.87	2.00	225.8	68.0	1.68	7420	13.95	1838.	.851	28.24	172.5	89.3	2201
5	Edge A	12.03	17.62	1.44	212.1	72.1	1.78	8352	6.07	2411.9	2.590	36.54	220.0	114.0	2201
6	A	12.18	15.37	2.25	187.1	81.9	2.02	10156	11.78	2116.	1.170	42.77	276.0	142.5	2193
7	A	12.33	13.87	1.50	171.1	89.5	2.22	11466	8.55	2046.	1.561	30.11	315.0	162.3	2192
8	A	12.49	12.62	1.25	157.8	97.2	2.40	12656	7.77	1646.	1.382	58.37	390.0	202.0	2192
9	Edge A	12.76	9.87	2.75	125.9	122.0	3.02	15756	20.20	4910.	1.584	52.24	458.0	236.5	2165
10	A	12.96	8.25	1.62	106.9	143.4	3.55	18076	15.10	3473.	1.496	61.12	538.0	278.0	2192
11	Edge D	8.45	10.00	2.96	84.5	181.3	4.50	21286	21.00	4556.	1.420	57.09	613.0	316.0	2201
12	D	8.65	8.12	1.88	70.4	218.0	5.40	23846	16.70	4803.	1.876	86.28	725.0	374.0	2201
13	Edge D	8.32	6.87	1.78	57.1	268.0	6.65	26746	18.90	7327.	2.525	86.23	836.0	432.0	2228
14	D	8.52	4.67	2.20	39.8	385.0	9.30	31386	30.10	4301.	.930	90.97	955.0	493.0	2237
15	Edge E	4.87	7.12	1.40	34.6	444.0	10.95	33386	13.05	5707.	2.850	75.35	1050.0	542.0	2246

Weight Ingot—4343 lbs.
Weight Ingot—1.935 Tons (2240 lbs.)
Analysis of Ingot—O. H. Steel.

C	.13
Mn.	.47
Si.	—
Phos.	.016
Sul.	.039

Heat No. 1315

Total ft.-lbs. used in rolling steel per ingot.
Average temperature of rolling = 2200°F.
Total lbs. steam engine running light between passes per ingot = 37.0 lbs.
Total lbs. steam per ingot 10.95 elongations = 1085.0 lbs.
Total Steam per ton (2240 lbs.) of steel and 10.95 elongations = 560 lbs.
Ingot dimensions 22"x20"x40.5".
Mean Section 18.5"x20.5".

culated from the area of the piece after each pass checked by means of direct measurement made on the table of the mill. The number of elongations is figured by dividing the length from the pass by the original length of the ingot, thus we have the elongation of the piece after each pass. The volume of displacement in cubic inches is equal to the product of the reduction in area in square inches multiplied by the length in inches before the pass. The percent reduction in area is the difference in area before and after any pass divided by the area before the pass. The thousand foot pounds used in rolling divided by the cubic inches displacement will give the thousands of foot pounds used in rolling per cubic inch of displacement.

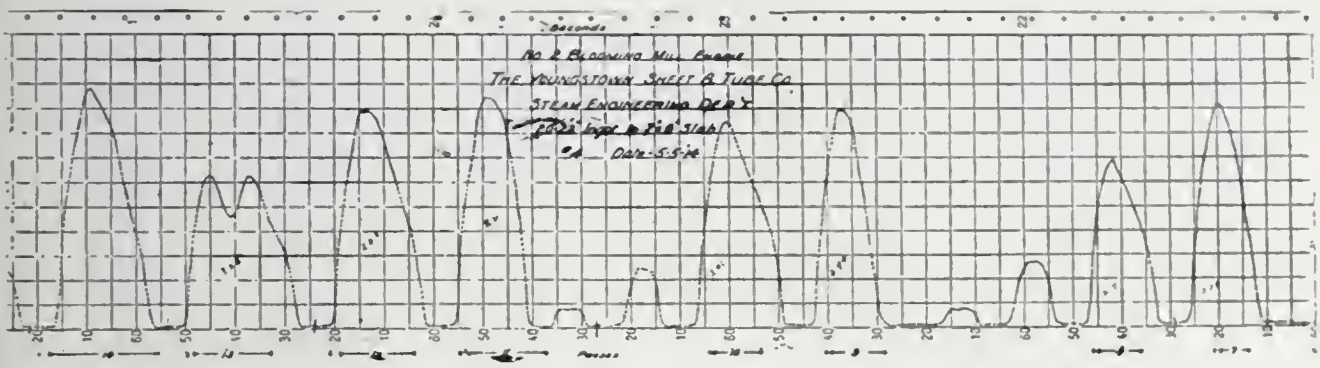

Fig. 14. Steam Flow Meter Chart.

The total steam per pass is determined from the indicator cards directly. The presssure at release of each card is measured and also at the same pressure during compression the volume is measured. To the original volume at release is added the clearance volume and to the volume obtained at the same pressure on compression is added the clearance volume. The difference of these two volumes represents the volume of steam actually used in the engine during that stroke. This quantity multiplied by the weight per cubic foot corresponding to that pressure will determine the dry steam consumed during that stroke. To this quantity should be added a certain percentage for losses due to leakage and condensation. It seemed advisable to use an addition of 30 percent to cover these losses. This value was assumed as the maximum possible quantity and for lack of any definite figures was adopted. By repeated tests with accurate steam flow meter having high speed clock it has been found that this value is correct. Figure 14 shows chart taken from steam flow meter.

The total steam consumed is the sum of the steam consumed per pass. This quantity divided by the tons in the ingot determines the amount of steam per ton. In last column of Table No. 2 is shown the temperature of the ingot for each pass. The weight of the ingot and analysis are also given on this table.

Table No. 3. Distribution of Work in Horse Power Seconds from Test No. 16.

TEST—BM—16 11-29-'13						TABLE 3
	H.P. Sec. $= \frac{\text{Work (Ft. lb.) Table 1}}{550}$					
Pass	Developed	Acceleration	Friction	Rolling	Displacement Cu. In.	Rolling H.P. Sec. per Cu. In. Displ.
1	8227	2900	821	4500	1840	2.445
2	7180	3940	600	2647	1180	2.240
3	6028	2620	695	2726	2260	1.160
4	5490	1671	458	3438	2140	1.605
5	9906	3059	2462	4390	932	4.710
6	8675	4165	662	3850	1804	2.130
7	6715	2462	536	3720	1310	2.838
8	10895	7090	780	2993	1190	2.515
9	11880	1732	1230	8940	3100	2.887
10	13060	5670	1072	6320	2320	2.722
11	13108	3342	1484	8280	3210	2.580
12	15770	5865	1168	8740	2560	3.410
13	17787	2936	1451	13300	.2900	4.590
14	16497	7340	1324	7830	4640	1.685
15	14030	2208	1451	10380	2000	5.180
Total	165248	57000	16194	92054	33386	Avg. 2.846

$$\frac{90837150 \text{ Ft. lb.}}{1980000} = 45.8 \text{ I. H. P. Hrs. Total.}$$

$$\frac{1085 \text{ lb.}}{45.8} = 23.6 \text{ lb. Steam per I. H. P. Hr.}$$

143 lb. Average Steam Pressure.
28 in. Hg. Average Vacuum.

In Table No. 3 is shown the horse power seconds developed, consumed in acceleration, in friction and in rolling. This is determined from work given in Table No. 1 by dividing these values by 550. The total steam used divided by the total indicated horse power hours gives the steam per *I. H. P.* hour.

Figure 15 shows a plot of the steam consumption per unit of elongation per ton of steel. The values of this curve are taken directly from Table No. 2. The dotted line marked "dry steam" is the amount figured from the indicator cards directly. The solid line marked "wet steam" is the dry steam values with 30 percent added for losses. This value of loss in the cylinder seems

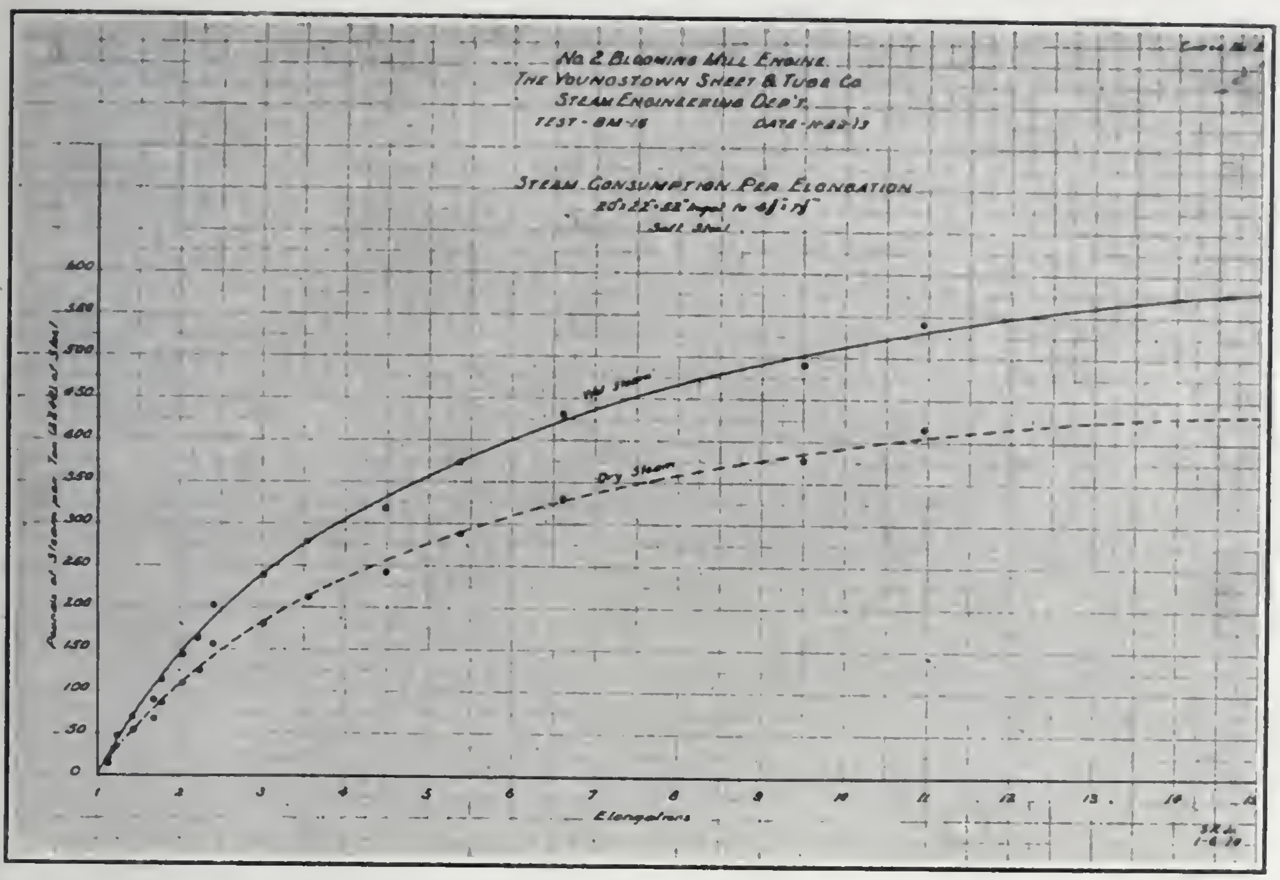

Fig. 15. Steam Consumption per Unit of Elongation 20×22 Ingot to 5×7 Bloom from Test No. 16.

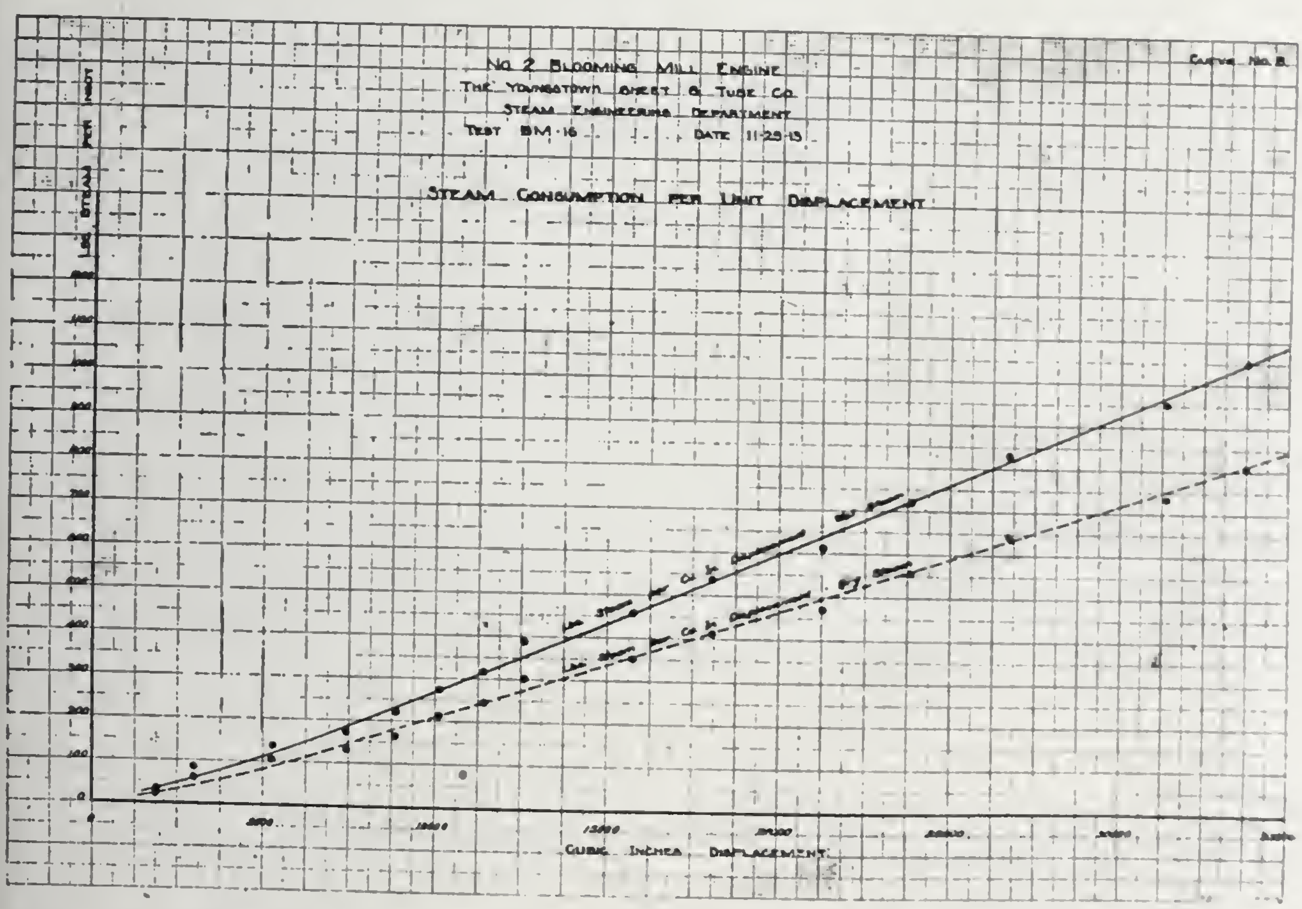

Fig. 16. Steam Consumption per Unit of Displacement 20×22 Ingot to 7×5 Bloom from Test No. 16.

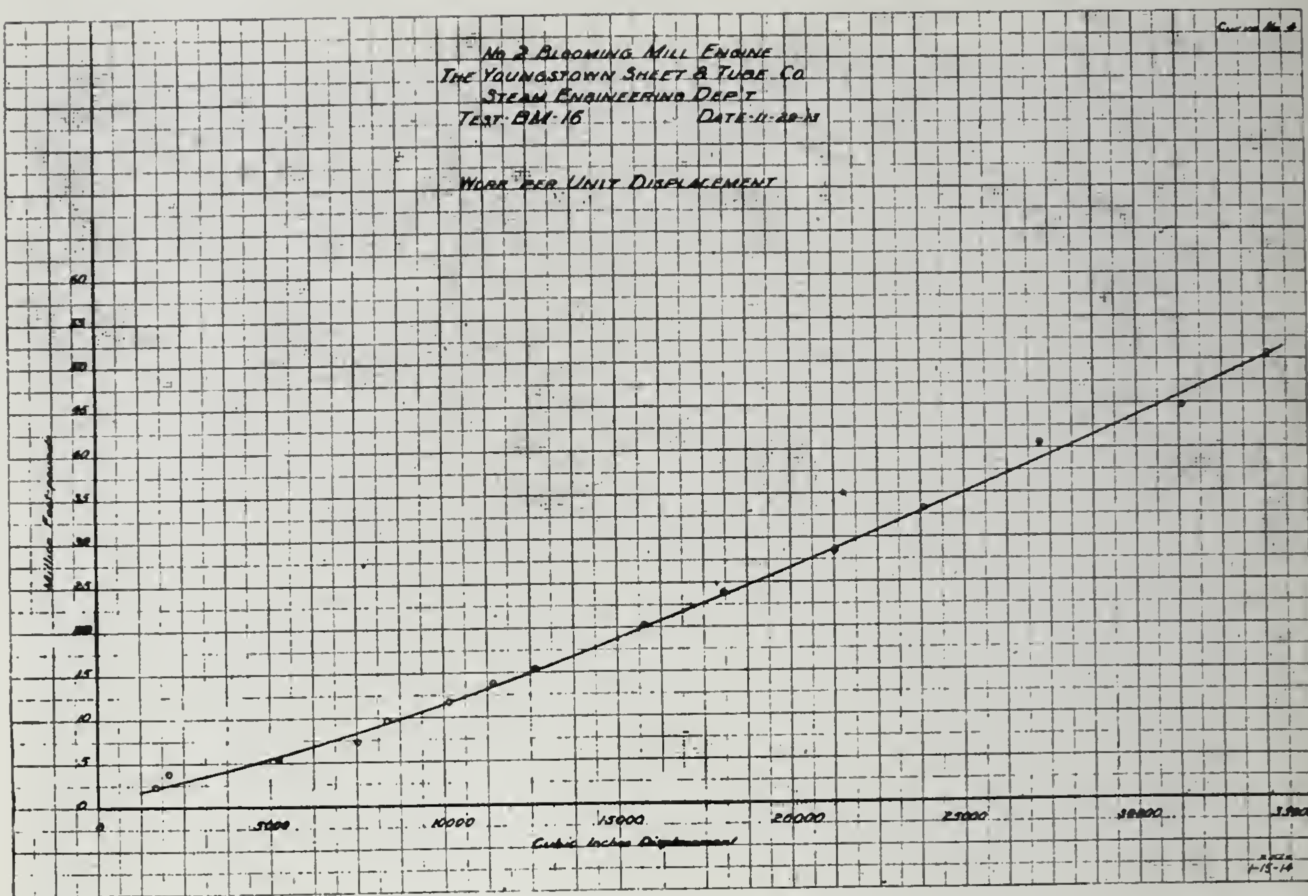

Fig. 17. Work per Unit of Displacement 20×22 Ingot to 5×7 Bloom from Test No. 16.

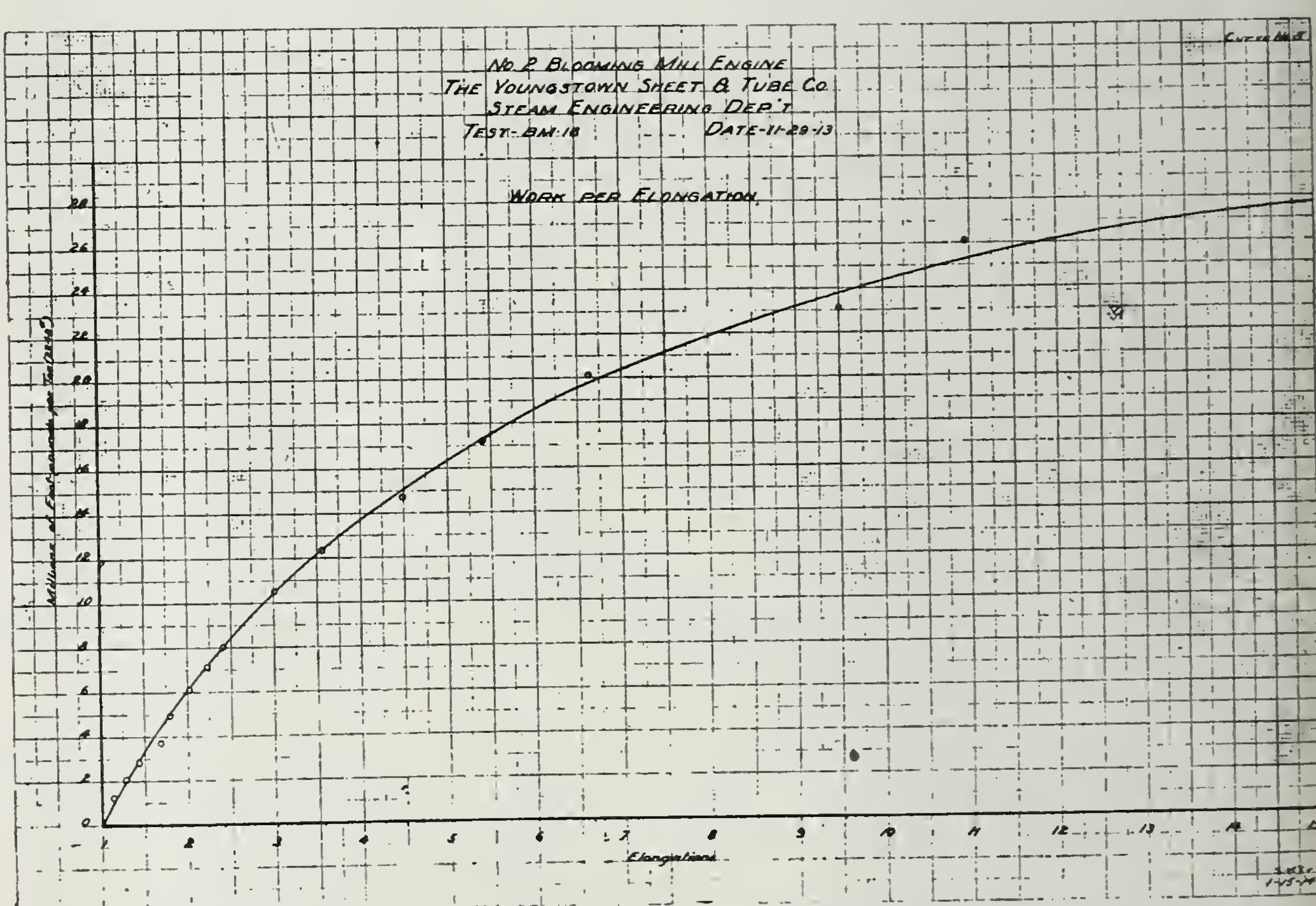

Fig. 18. Work per Unit of Elongation 20×22 Ingot to 5×7 Bloom from Test No. 16.

excessively high, but in order to be amply safe, it was used on this test. Since making this test however, we have run several very careful tests with a Hallwachs Arc Recording Steam Flow Meter and have obtained values checking this. We are therefore, convinced that the loss due to condensation, leakage, etc. is about 30 percent. The steam consumption as shown on Fig. 15 by the solid line is therefore correct.

Figure 16 represents the pounds of steam consumed per cubic inch of displacement. This plot is made directly from Table No. 2. The solid and dotted lines have the same meaning as in Fig. 15.

Figure 17 represents the work done per cubic inch of displacement and is plotted from Tables No. 1 and No. 2 directly. The work here shown represents the actual work used in deforming the steel.

Figure 18 is plotted from Table No. 1 and Table No. 2, and represents the work done in deforming the steel per unit of elongation per ton. Figures 19 and 20 represent average steam consumption per ton per unit of elongation and also the work done per unit of elongation of three complete ingots worked up separately.

In Fig. 19 the shaded area between the two top curves, contains the supposed actual curve of steam consumption, the maximum and minimum values being represented by the two curves. The point marked steam consumption by heat balance from condenser is figured from the amount of water flowing over the weir and the average temperatures in the condenser as shown in Fig. 10. The exhaust steam was assumed to have 25 percent moisture in it. It is quite remarkable that the value should check so closely with other methods of obtaining the steam as the temperatures in the condenser were constantly changing and the thermometer exhibited a certain time lag for which it was necessary to allow.

CONCLUSIONS

By referring to Table No. 1, it will be seen that 34.5 percent of the total available work is consumed in accelerating and retarding the rotating and reciprocating parts, 9.8 percent is used in friction and only 55.7 percent is actually consumed in de-

forming the steel. It thus appears that an inordinate amount of work is consumed by the engine in accelerating and retarding the moving parts. This amount is due to the weight of moving parts used and the excessive amount of counterbalancing done, this being 60 percent of the reciprocating parts.

Tests which have been made on other engines, would indicate that this amount of power may be larger than necessary. There should be little or no trouble in bringing this value down to not more than 15 percent. Engines have been tested where this quantity was even lower.

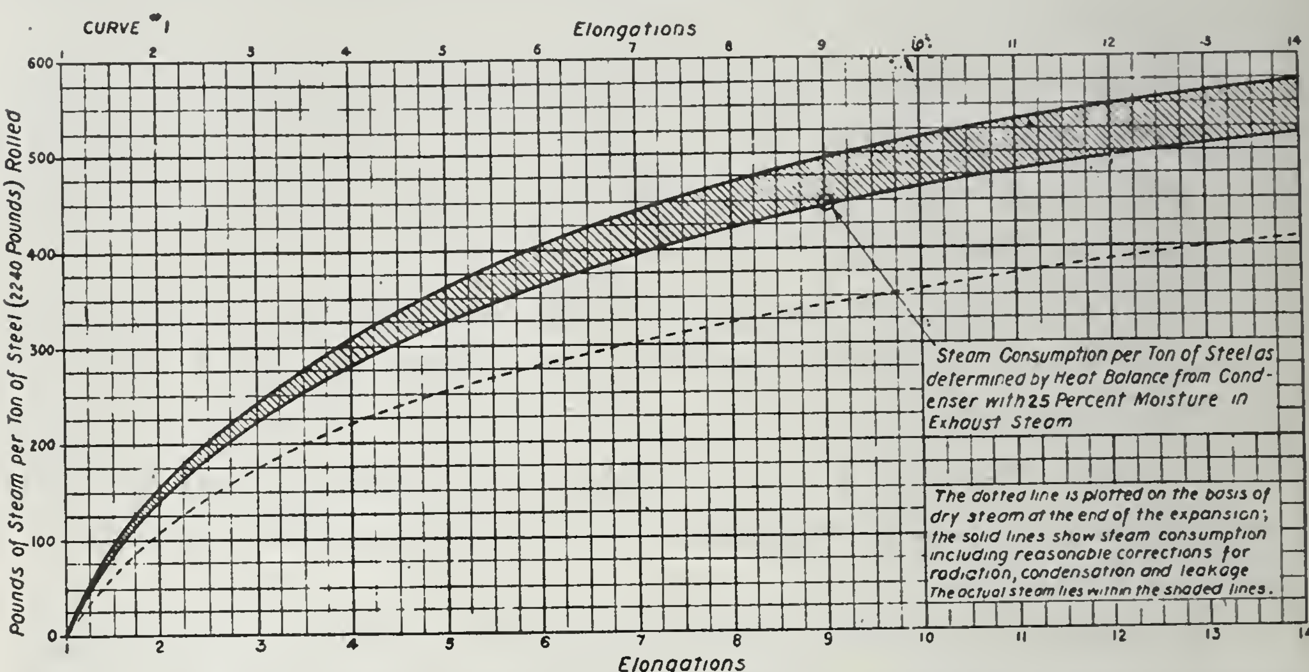

Fig. 19. Steam Consumption per Unit of Elongation from Average of Three Ingots.

It might be possible to build an engine with much lighter moving parts and providing suitable means for increasing and decreasing the counterbalance weights, so as to produce the required smooth running without consuming such a large amount of power.

It must be borne in mind however, that the engine in question runs without the slightest vibration and has shown no wear on boxes, pins, or bearings. This of course, is a desirable feature, but we must not be lead astray by these conditions of running to a point where we constantly spend too much in steam consumption in order to obtain an absolutely smooth running engine.

The amount of power consumed in friction, 9.8 percent, is exceptionally low, the values of other engines running from 14

to 25 percent. This low value is obtained by large short bearings properly lubricated and perfect alignment. The pinions and bearings are also of the highest type of construction being carefully machined and aligned. The couplings used are of special design and machined to eliminate all lost motion and reduce the friction and wear to a minimum. The cut pinions, special couplings and bearings, we believe reduces the friction very materially.

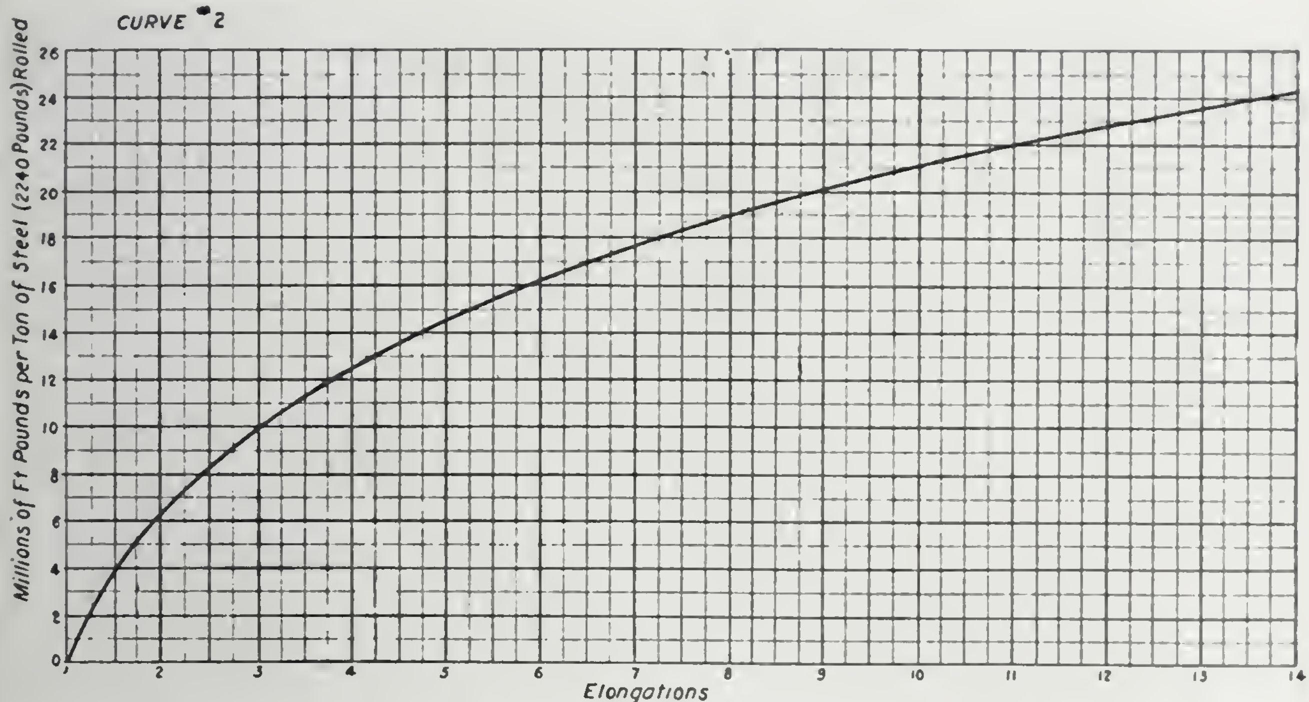

Fig. 20. Work per Unit of Elongation from Average of Three Ingots.

The steam consumed per *I. H. P.* hour was found to have a maximum value of 23.6 percent after adding the 30 percent for condensation, leakage, etc. In spite of this large addition, the average value of steam consumed per *I. H. P.* hour exhibits a value of about 21 lb. per *I. H. P.* hour. This value compares very favorably and in fact, is almost identical with the steam per *I. H. P.* hour determined for high class three high mills, while the best steam consumption yet obtained in this country for reversing condensing engines was in the neighborhood of 35 lb. With this exceptionally good steam consumption, if the power required to accelerate the moving parts were reduced to a reasonable amount, say 15 percent, the steam consumption per unit of elongation per ton of metal would be reduced nearly 30 percent, thus giving a steam consumption which would be absolutely phenomenal for this country. The steam consumption as obtained per unit of elongation compares very favorably

with tests of other engines which are operating in this country and also with engines abroad. In fact, the reduction of the amount of power consumed in acceleration would produce a steam consumption per unit of elongation which would be better than the value as given by Puppe, as the best practice for condensing engines in Europe. The correct value of steam consumption per *I. H. P.* hour as shown by steam meter is 18 lb. This is indeed, we believe, better than any other yet obtained.

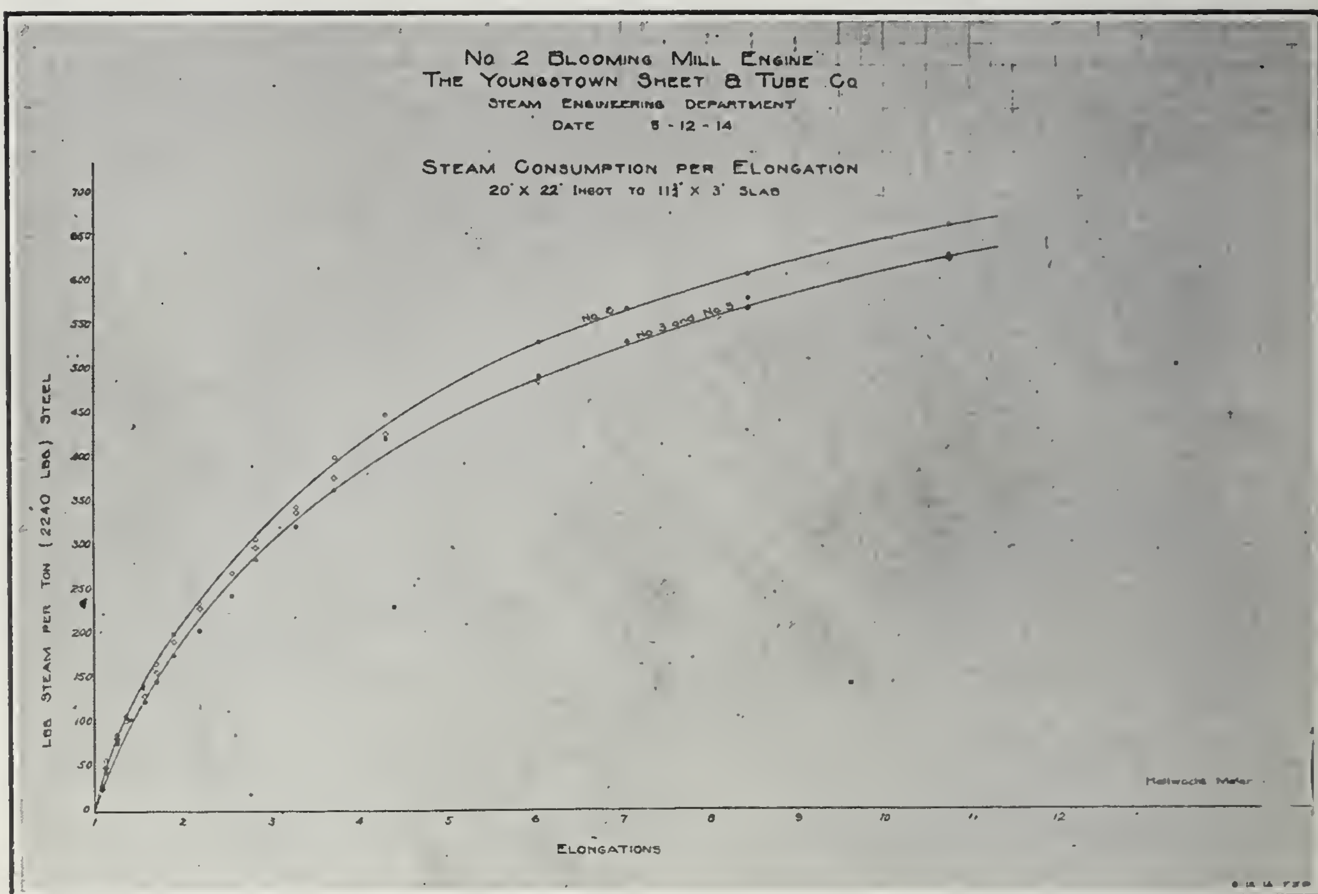

Fig. 21. Steam Consumption per Unit of Elongation 20×22 Ingot to 11¾×3 Slab.

The addition of 30 percent to the dry steam as figured from the cards may seem excessive for an engine of this class, but in the absence of definite knowledge at the time this engine was run, this value was used. We have since learned that this value is approximately correct.

The saving due to the steam held in the cylinder during compression was found to be about 10 percent. With the ordinary type of gear there is practically no steam saved in compression and this feature is usually dropped.

The engine has been run non-condensing and the steam consumption determined with the result that the steam used is approximately 25 percent higher than when running condensing,

thus by condensing a reversing engine, it is possible to obtain a saving of 25 percent. With a simple engine exhausting into a low pressure turbine, even when equipped with a regenerator, it is very doubtful if it is possible to effect an equal saving. Where it is possible to use the exhaust from a reversing engine for heating the boiler feed water, it is of course, the most efficient way to use the heat in the exhaust steam.

It has been stated that it is impossible to produce a high vacuum in the cylinders of the reversing engine, but this fact has been clearly disproved by this engine. A vacuum of 25 inches in the low pressure cylinder is obtained with 28 inches in the body of the condenser.

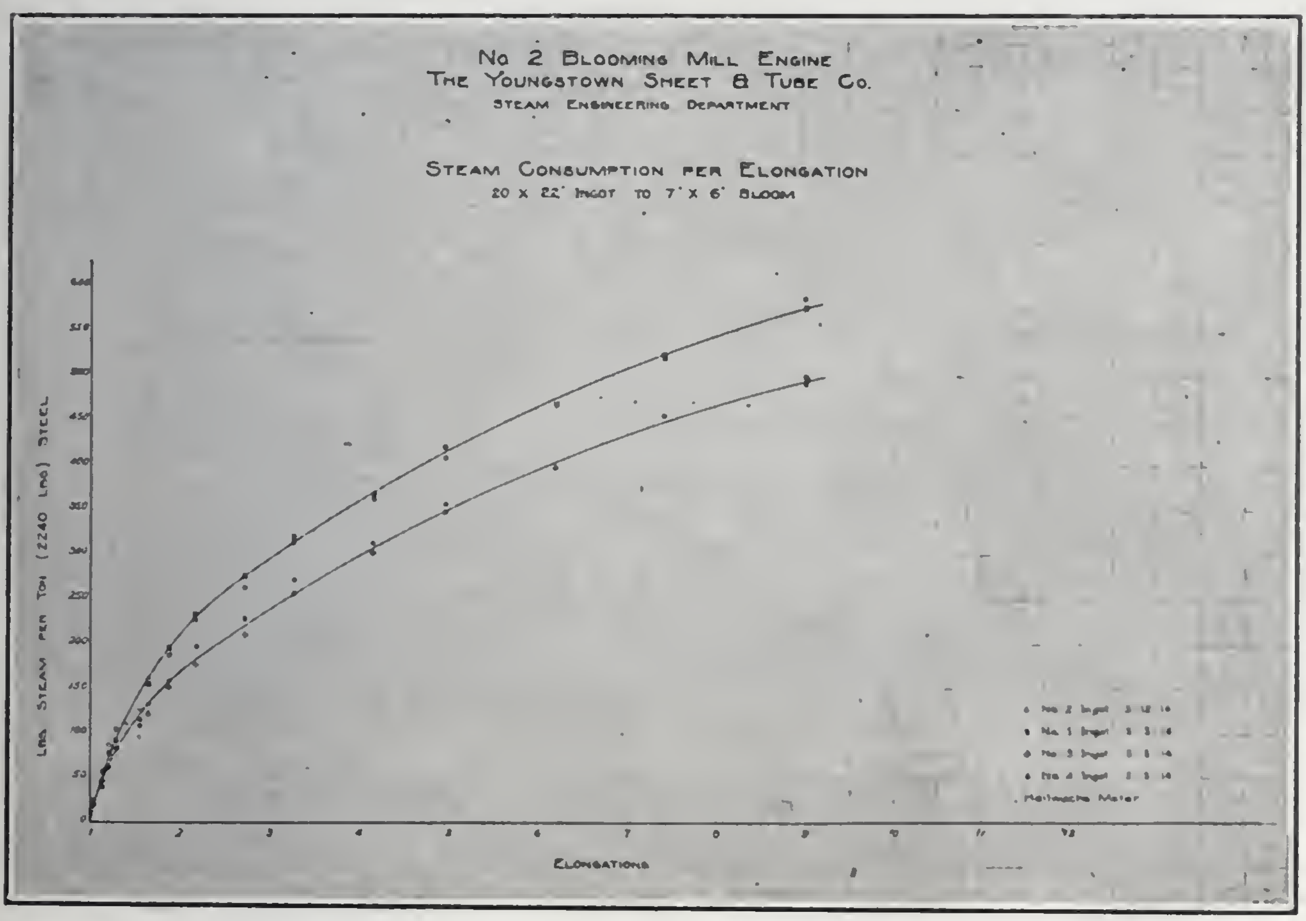

Fig. 22. Steam Consumption per Unit of Elongation 20×22 Ingot to 7×6 Bloom.

The explanation of the remarkable steam consumption of this engine, is believed to be in the single lever control and the consequent impossibility of using a large amount of steam for "plugging" the engine and throttling the steam for controlling the engine, together with well set valves giving high compression. It will be noticed from an inspection of Fig. 11, that these cards exhibit a much greater compression than is found on

engines with the double lever control, which also represents a saving.

The engine has been found to reverse quickly, despite the prediction that this would not be the case with a single lever control.

After repeated observations, it has been found that the engine will change from a speed of 60 r. p. m. in one direction to 30 r. p. m. in the opposite direction in less than 2½ seconds. The engine has rolled 500 ingots in 12 hours with an average

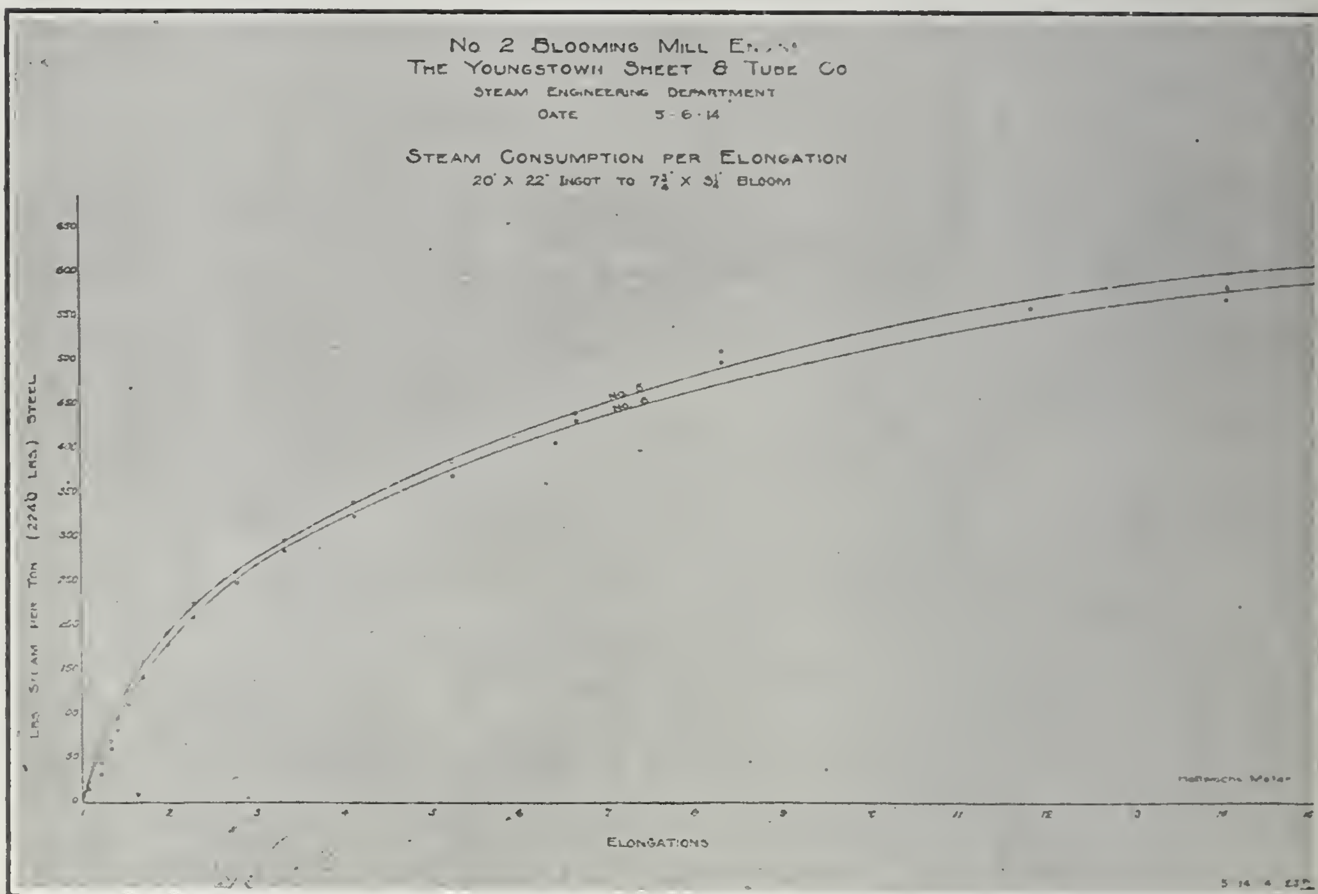

Fig. 23. Steam Consumption per Unit of Elongation 20×22 Ingot to 7¾×3¼ Bloom.

elongation of 8, proving that it is possible to manipulate the engine and mill very quickly. The weight of these 500 ingots was 1298 tons and no ingots were rolled in less than 15 passes. The average time of rolling a 2½ ton ingot as described in this test was 85 seconds from the time it reached the rolls until it left the rolls. The time of manipulation and of actual rolling is found to be about equal, i. e. approximately 42½ seconds in actually deforming the steel and an equal amount in manipulating the piece.

From observations taken on the control lever of the en-

gine, it was found that it requires approximately 3/5 of a second to move the lever through its entire travel, and 1½ seconds are required from the beginning of the movement of the reversing lever until the links are fully reversed. From ½ to 1 second is the time required for the links to reach their new extreme position after the lever has reached its new extreme position.

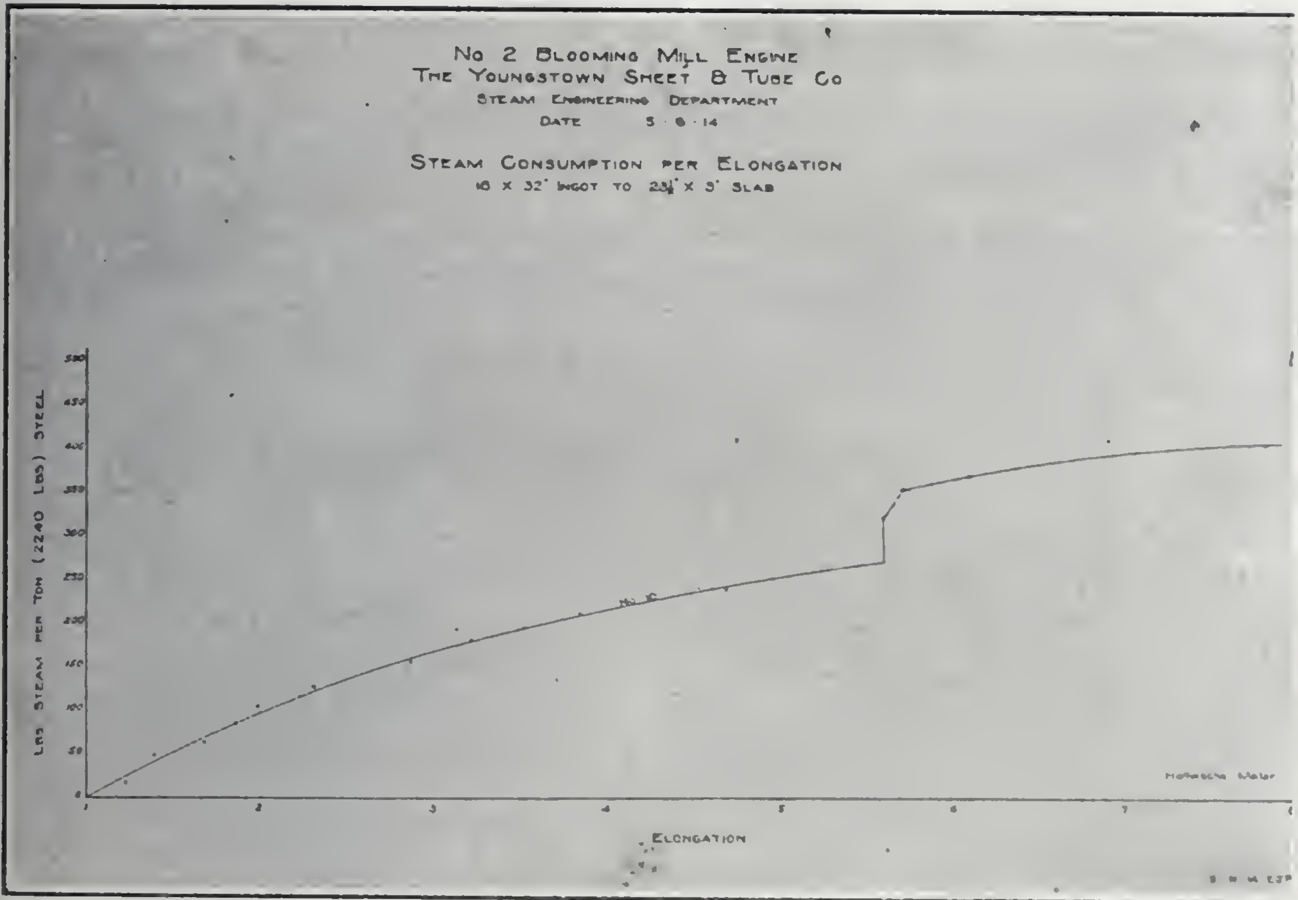

Fig. 24. Steam Consumption per Unit of Elongation 18×32 Ingot to 23½×3 Slab.

By a study of Fig. 12, the relative operation of the reversing cylinder and throttle valve will be seen. At the beginning of passes No. 2 and No. 3 will be seen the action of the gear when operating slowly, the piece entering the rolls three strokes after the jack is moved from its center position. The throttle valve opens one and one-quarter strokes after moving the cylinder.

At the beginning of pass No. 5 the piece enters the rolls at the same time the reversing gear is moved off center. This condition is found as the engine had been drifting after the fourth reversal. The engine was thus running in the proper direction and the valve was opened to admit steam for rolling the piece.

A study of these lines will enable us to definitely study the conditions of valve motion at each reversal or increase in load.

From a study of charts in Fig. 10, it will be seen that the condenser maintains a remarkably uniform vacuum during the rolling of the piece. The temperature of the tail water varies 10 or 15 degrees during the rolling, but drops immediately to its original value, demonstrating that the condenser is amply large to handle the loads and that a barometric condenser is a quick and efficient means of condensing large, intermittent, variable quantities of steam.

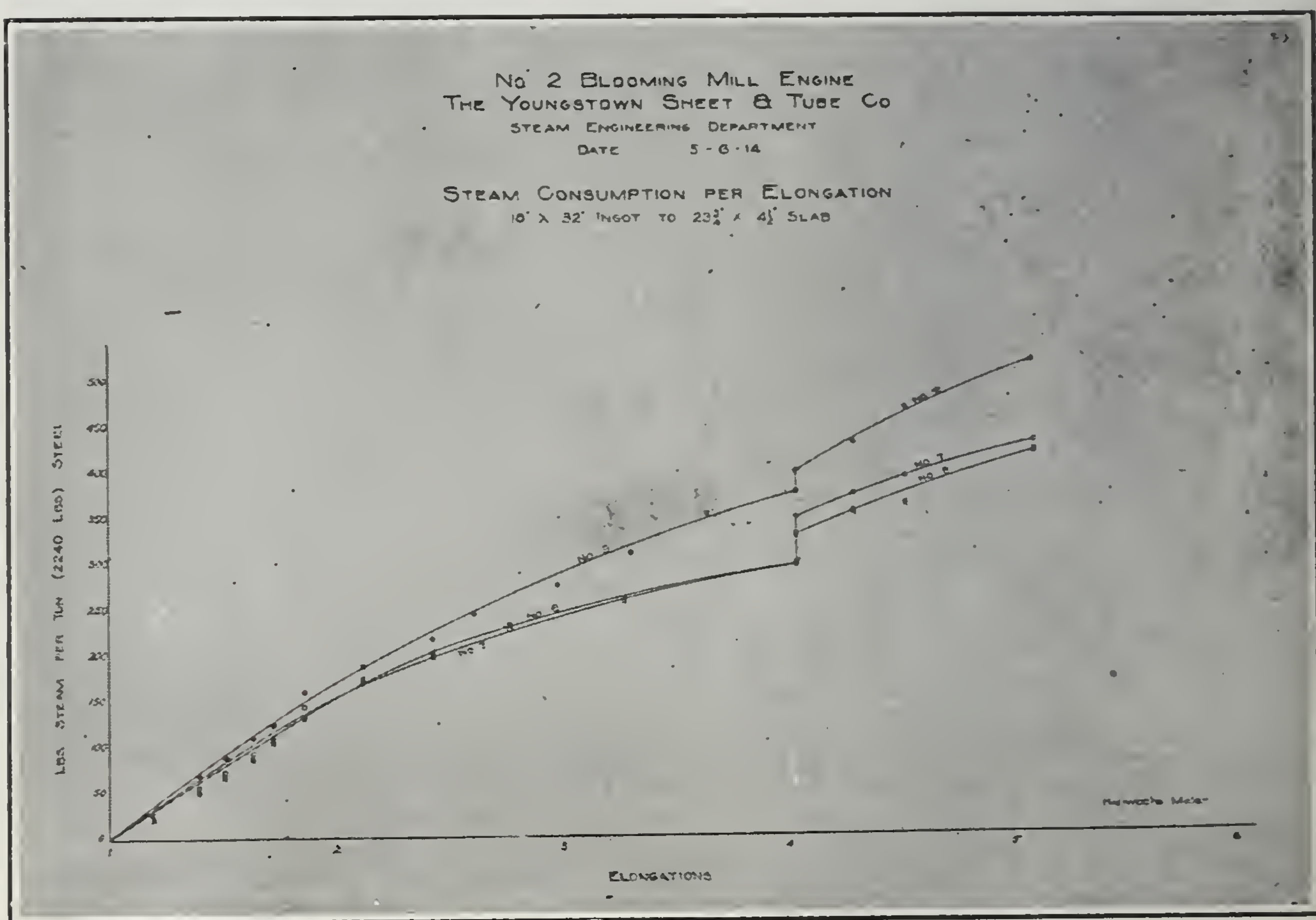

Fig. 25. Steam Consumption per Unit of Elongation 18×32 Ingot to 23¾×4½ Slab.

Figures 21 to 27, inclusive, are plots of steam consumption as accurately measured by recording steam meter for various sections rolled and for several sizes of ingots and blooms.

From a study of these figures, it appears as though a larger amount of steam was required per ton for a given number of elongations when rolling slabs than is required when rolling squares or approximately a square section with the same number of elongations when both are rolled from an ingot that is

approximately square. Compare Fig. 21 and Fig. 22. Both of these represent the steam consumption when rolling a 20 in. by 22 in. ingot. This difference may appear self-evident due to the difference in cubic inches of metal displaced, but the fact is worthy of note.

In Figs. 24, 25 and 27 the effect of idle passes upon the steam consumption is clearly shown. Figures 24 and 26 exhibit the effect of edging passes where a very small amount of metal

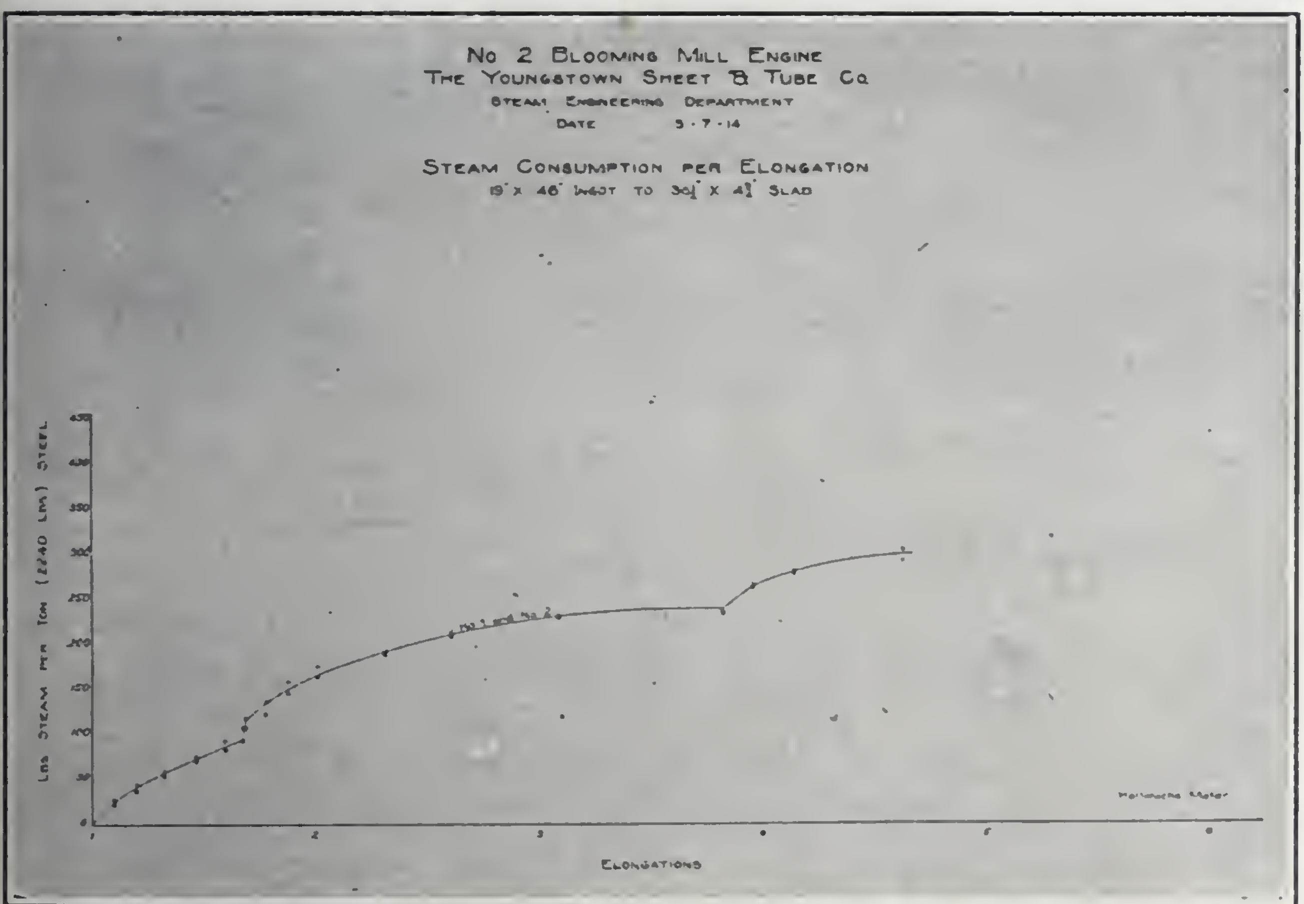

Fig. 26. Steam Consumption per Unit of Elongation 19×46 Ingot to 36½×4¾ Slab.

is displaced. These curves are all plotted from the results of several tests. In several instances the curves represent more ingots than are actually shown. When two or more ingots were plotted and the points were found to fall on the same locations, one curve only was plotted. For every plot, however, enough ingots were taken to make the curves representative.

Figures 21, 22 and 27 exhibit clearly the difference in steam used by different operators, all being considered expert and experienced engineers.

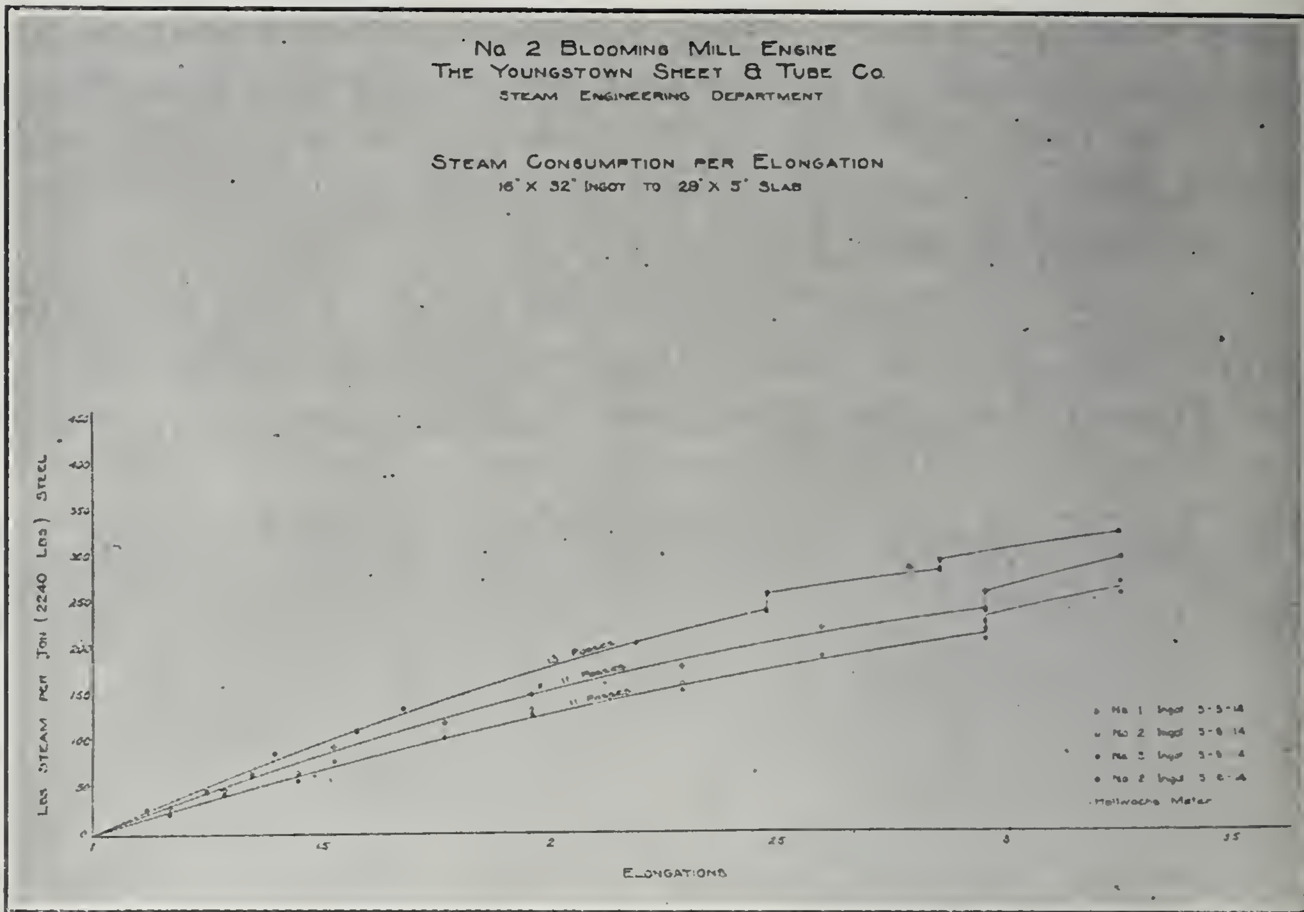

Fig. 27. Steam Consumption per Unit of Elongation 16×32 Ingot to 29×5 Slab.

Table No. 4 shows the amount of steam used for various sections as actually measured by steam meter, the values given being the average of several observations for each size.

Table No. 4. Pounds of Steam per Ton for Rolling Various Sizes of Ingots for Different Elongations.

Table 4.	Pounds of Steam per Ton for Rolling Various Sizes of Ingots for Different Elongations.					
No.	Size		Number of Elongations	Lbs. Steam per Ton	Lbs. Steam per Ton at	
	Ingot	Bloom			5-Elong.	9-Elong.
A	20"×22"	11¾"×3"	11.5	643	444	591
B	20"×22"	7¾"×3¼"	15.0	600	375	505
C	20"×22"	7"×6"	9.0	495	350	495
D	18"×32"	23¾"×4½"	5.0	420	420	
E	16"×32"	29"×5"	3.25	280		
F	19"×46"	36½"×4¾"	4.75	300		
G	18"×32"	23½"×3"	7.5	410	256	

From steam integrator, with readings taken every 24 hours, it has been found that the average steam consumption per ton of steel rolled for one week is 418 lb. per ton. This value includes all steam used in the regular operation of the mill during 24 hours. The sizes of material handled include all

sizes as shown in Figs. 21 to 27 in varying proportions. No attempt has been made to determine the proportion of each size rolled, although more than 50 percent of the production was 6 in. by 7 in. blooms from 20 in. by 22 in. ingots.

Table No. 5. Pounds of Steam per Ton for Rolling Various Sizes of Ingots.

Table 5.	Pounds of Steam per Ton for Rolling Various Sizes of Ingots.				
No.	Size		Elongations	Lb. Steam per ton	Remarks
	Ingot	Bloom			
A	20″×22″	7″×6″	9.04	587	Cold ingot.
B	20″×22″	7″×6″	9.04	490	Hot ingot.
C	20″×22″	7″×6″	9.04	497	Good rolling.
D	20″×22″	7″×6″	9.04	520	New engineer.
E	20″×22″	7″×6″	9.04	518	New engineer.
F	20″×22″	7″×6″	9.04	575	Bad rolling.
G	20″×22″	7¾″×3¼″	15.1	767	New engineer.
H	20″×22″	7¾″×3¼″	15.1	610	Good manipulation.
I	20″×22″	11¾″×3″	10.75	694	New engineer.
J	20″×22″	11¾″×3″	10.75	625	Good manipulation.
K	18″×32″	23¾″×4½″	5.13	522	Good rolling—cold.
L	18″×32″	23¾″×4½″	5.13	423	Good rolling—hot.
M	19″×46″	36½″×4¾″	4.63	356	Bad rolling.
N	19″×46″	36½″×4¾″	4.63	292	Good rolling.

It is very interesting to note the excess of steam which is consumed per ton, due to difficulty with manipulation of the piece and also to the piece not entering the rolls properly. With very little trouble the steam consumption per ton can be increased 30 percent. It has also been found that one operator may use 10 or 15 percent more steam than another and yet both may be considered expert engineers with a large amount of practice upon this mill.

Table No. 5 will give some idea of the increase which may be met with when rolling various sizes under different conditions of temperature and handling of the piece.

During one month of operation the steam consumption of this mill was 473 lb. per ton of steel rolled, which we feel to be a very fair check upon the observations made, both on 24 hour runs and for individual ingots. With a moderate amount of ordinary difficulty in manipulation and operation, it thus appears that this mill should consume less than 500 lb. of steam per ton of steel rolled constantly.

Table No. 6. Results as Calculated by Mesta Machine Company from Test No. 9.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	
Pass No.	Dimensions of Piece Inches	Area of Section Square Inches	Reduction in Area Square Inches	Reduction In Area Percent	Length of Bloom After Pass. Inches	Elongations	Total Pounds Steam for 2240 Pounds Steel	Pounds Per I.H.P. Hour	Seconds While Piece Was in Pass	Million Foot Pounds Developed While Piece Was in Pass	Average I.H.P. While Piece was in Pass	Average Piston Speed Ft. Per Min.	Max. M.E.P. Referred to Low Pressure Piston Lb. Per Sq. In. H.P.	L.P.
0	19 x 16¼	310			71									
1	18¼ x 16¼	297	13	4.2	74	1.04	16	19	1.25	3.5	5100	520	34	18
2	16¾ x 16⅞	283	14	4.7	78	1.10	34	25	1.88	4.1	3950	560	33	26
3	16¾ x 16½	275	8	2.8	80	1.13	53	15	1.25	2.5	3650	480	33	21
4	15 x 17½	262	13	4.7	84	1.18	68	23	1.13	3.6	5800	430	35	22
5	13⅝ x 18⅜	250	12	4.6	88	1.24	80	17	1.5	3.5	4250	430	35	23
6	12 9/16 x 18⅜	230	20	8.0	96	1.35	110	24	1.88	6.1	5900	670	32	20
7	14¾ x 13⅞	204	26	11.4	108	1.52	130	19	1.5	4.5	5450	390	37	25
8	13¼ x 13⅞	184	20	9.8	120	1.69	151	23	2.18	3.8	3150	650	39	26
9	12 11/16 x 13⅞	176	8	4.3	125	1.76	170	17	2.13	4.1	3500	600	23	22
10						IDLE PASS								
11	10½ x 13⅞	146	30	17.1	151	2.12	197	18	1.88	4.9	4750	480	33	25
12	8 9/16 x 13⅞	119	27	18.6	184	2.59	220	25	2.18	4.9	4100	430	39	27
13	9⅞ x 9⅛	90	29	24.3	245	3.45	260	22	4.0	8.9	4050	500	31	27
14	8¼ x 9⅛	75	15	16.7	293	4.13	285	17	2.88	6.4	4050	750	31	27
15	6⅞ x 9⅛	63	12	16.0	349	4.93	325	25	4.5	7.0	2800	690	30	24
16	5 9/16 x 9⅛	51	12	19.0	432	6.10	360	22	4.5	7.8	3150	740	34	27
17	7¼ x 6⅛	44	7	13.7	505	7.10	398	20	4.0	9.6	4350	910	33	25

Average Pounds per I. H. P. Hour = 21. Weight ofIngot = 6200 Pounds. Average Temperature = 2030 °F.

Table No. 7. Distribution of Work as Calculated by Mesta Machine Company from Test No. 9.

1	2	3	4	5	6	7	8	9	10	11
Pass	Elongations	Area (in Square Inches) of M. E. P.—Stroke Diagram					Percentages			Available Work per Pass in Million Foot Lbs. Per 2240 Lbs. Steel
		Positive	Negative	Friction	Friction Plus Negative	Available for Rolling	Available	Acceleration	Friction	
1	1.04	2.64	1.67	.66	2.33	.31	12	63	25	.20
2	1.10	2.44	1.55	.52	2.07	.37	16	63	21	.23
3	1.13	2.96	1.58	.70	2.28	.68	23	53	24	.43
4	1.18	2.04	.94	.38	1.32	.72	35	46	19	.45
5	1.25	2.32	1.04	.32	1.36	.96	42	44	14	.61
6	1.35	3.90	2.12	.70	2.82	1.08	28	54	18	.68
7	1.52	3.40	.92	.76	1.68	1.72	51	27	22	1.09
8	1.69	2.92	1.39	.52	1.91	1.01	35	47	18	.64
9	1.76	2.54	1.91	.58	2.49	.05	2	75	23	.03
10					Idle Pass					
11	2.12	4.66	1.20	.70	1.90	2.76	59	26	15	1.74
12	2.59	3.05	.69	.58	1.27	1.78	58	23	19	1.12
13	3.45	5.74	1.41	1.16	2.57	3.17	56	24	20	2.00
14	4.13	4.70	1.82	.70	2.52	2.18	46	39	15	1.38
15	4.93	4.93	1.10	.66	1.76	3.17	64	22	14	2.00
16	6.10	5.08	1.52	.98	2.50	2.58	51	30	19	1.63
17	7.10	5.84	2.35	1.08	3.43	2.41	42	40	18	1.52
						Average	39	42	19	

Friction M. E. P. on one L. P. Piston = 6 lbs. per sq. in. One L. P. Piston Area = 4340 sq. in. 1 sq. in. Area of M. E. P.—StrokeDiagram = 1,740,000 ft. lbs.

Weight of Ingot = 6200 lbs. Average Temperature = 2030 °F. Analysis of Heat No. 4195 : C—.14, Mn—.50, Phos.—.075, S.—.034.

Table No. 8. Distribution of Work as Calculated by H. C. Siebert from Test No. 7.

Pass.	Positive I. H. P. Seconds.	Friction I. H. P. Seconds.	Accel. Loss I. H. P. Seconds	Available Work I. H. P. Seconds.	Friction %	Accel. Loss %	Available Work. %
1	6826	1300	1909	3617	19.0	28.0	53.0
2	9024	1655	3857	3512	18.3	42.8	38.9
3	8453	2127	2494	3832	25.1	29.5	45.4
4	4121	591	526	3004	14.4	12.7	72.9
5	10447	1891	6630	1926	18.1	63.5	18.4
6	6006	1064	1306	3636	17.7	21.8	60.5
7	12172	2718	4312	5142	22.3	35.5	42.2
8	8727	1182	1946	5599	13.6	22.3	64.1
9	16315	2364	3721	10230	14.5	22.8	62.7
10	11914	1654	3952	6308	13.9	33.2	52.9
11	18281	2600	3364	12317	14.2	18.4	67.4
12	13012	1891	3087	8034	14.5	23.7	61.8
13	19625	2127	3690	13808	10.8	18.8	70.4
14	19262	2836	7698	8728	14.7	40.0	45.3
15	16434	3546	3107	9781	21.6	18.9	59.5
16	15773	4019	8553	3201	25.5	54.2	20.3
17	14714	3900	1749	9065	26.5	11.9	61.6
TOTAL	211106	37465	61901	111,740	17.8	29.3	52.9

Table No. 9. Distribution of Work as Calculated by H. C. Siebert from Test No. 15.

Pass.	Positive I. H. P. Seconds.	Friction I. H. P. Seconds.	Accel. Loss I. H. P. Seconds.	Available Work. I. H. P. Secs.	Friction %	Accel. Loss %	Available Work. %
1	6140	945	2896	2299	15.4	47.2	37.4
2	4980	827	1956	2197	16.6	39.3	44.1
3	7976	2600	2695	2681	32.6	33.8	33.6
4	6267	922	2616	2729	14.7	41.7	43.6
5	8545	1418	6416	711	16.6	75.1	8.3
6	7487	827	1810	4850	11.0	24.2	64.8
7	13260	3456	5615	4189	26.7	42.1	31.2
8	11583	1418	4204	5961	12.2	36.3	51.5
9	15555	1537	4379	9659	9.9	28.2	61.9
10	13195	1655	4939	6601	12.5	37.4	50.1
11	18898	2837	4310	11751	15.0	22.8	62.2
12	14706	1773	4007	8926	12.0	27.2	60.8
13	21613	2128	4541	14944	9.8	21.0	69.2
14	34997	6146	20821	8030	17.6	59.4	23.0
15	20911	5201	5809	9901	24.8	27.8	47.4
TOTAL	206113	33690	77014	95409	16.4	37.3	46.3

In Tables No. 6 and 7 are seen the tabulation of data taken from another ingot and are similar to the data given for the test described. Tables No. 8, 9 and 10 are the results as obtained from two other ingots and calculated by Mr. Seibert.

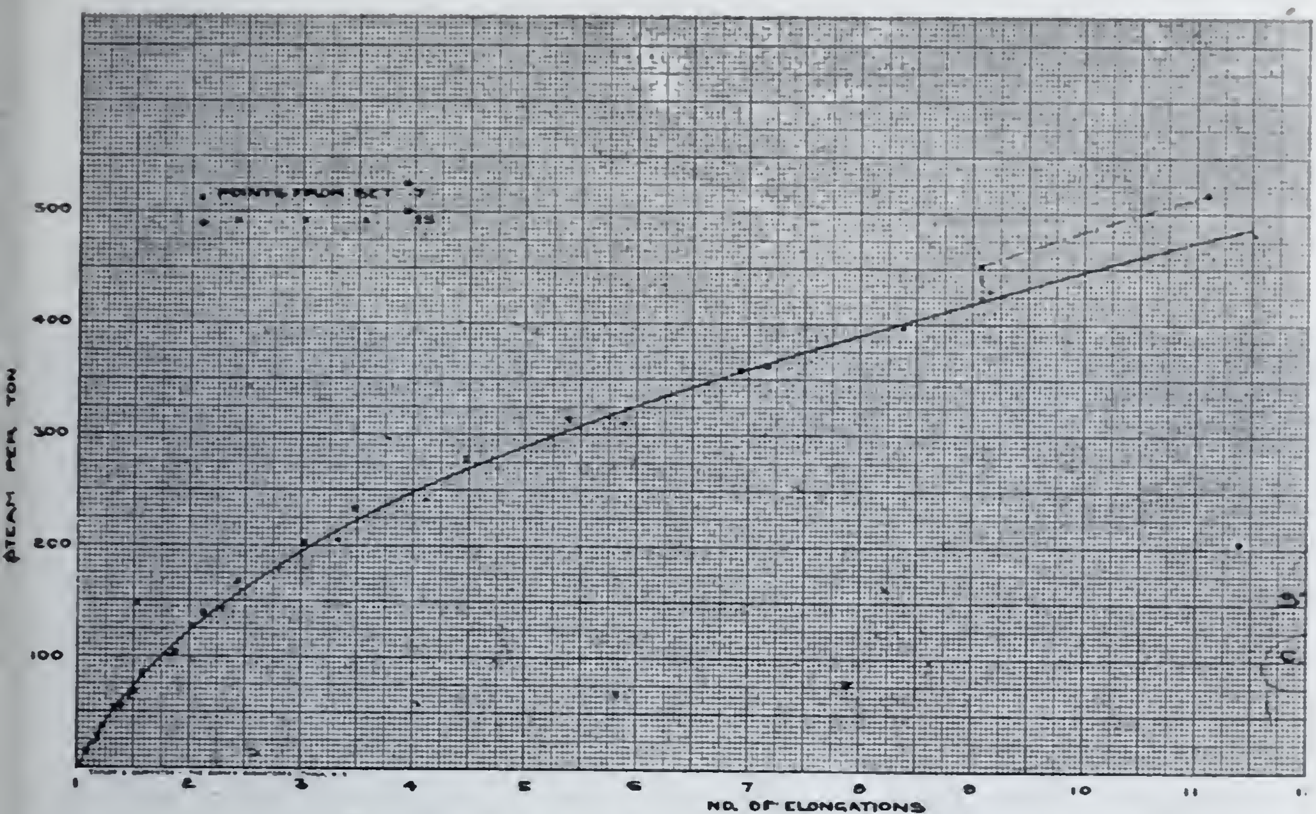

Fig. 27-a. Steam Consumption per Ton per Unit of Elongation for 20 by 22 in. Ingot rolled to 4⅞ by 6⅜ in. from Set No. 7 and Set No. 15 Cards.

Figure 27-a represents the pounds of steam consumed per ton of steel rolled, per unit of elongation, as calculated by Mr. H. C. Siebert. This curve represents the results of observations taken for two separate ingots.

Figure 27-b represents the indicated horse power seconds per ton per unit of elongation for the same two ingots.

Figures 27-c and 27-d represent the analysis of the cylinder performance. These curves clearly show the uniform distribution of work in the various cylinders and the cylinder events. The pounds of steam per stroke is also shown on these sheets. From a careful study of these two curves an accurate conception of the cylinder performance and events is easily obtained.

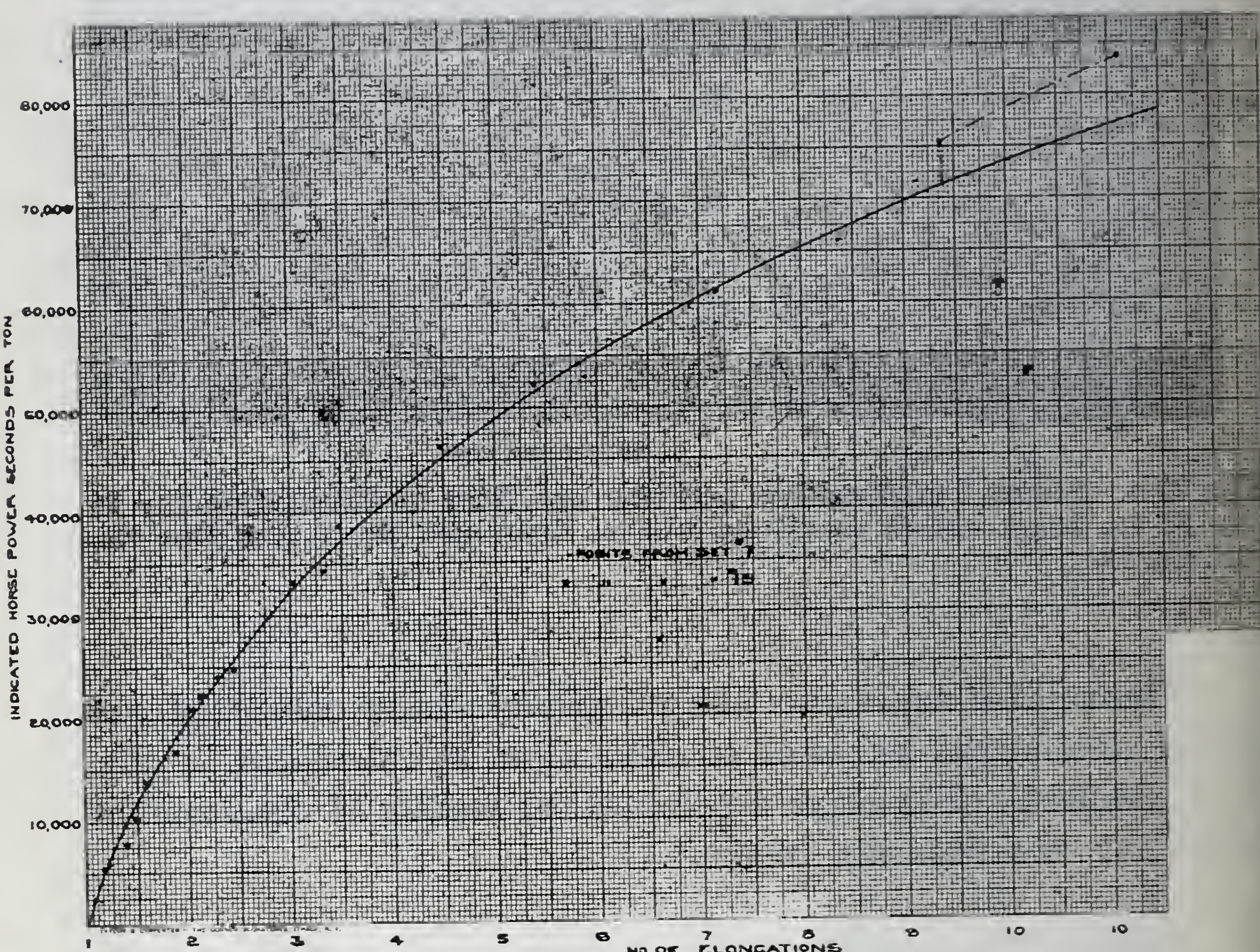

Fig. 27-b. Indicated Horse Power Seconds per Ton of Steel per Unit of Elongation for 20 by 22 in. Ingot rolled to 4⅞ by 6⅝ in. from Set No. 7 and rolled to 5⅛ by 7 in. from Set No. 15.

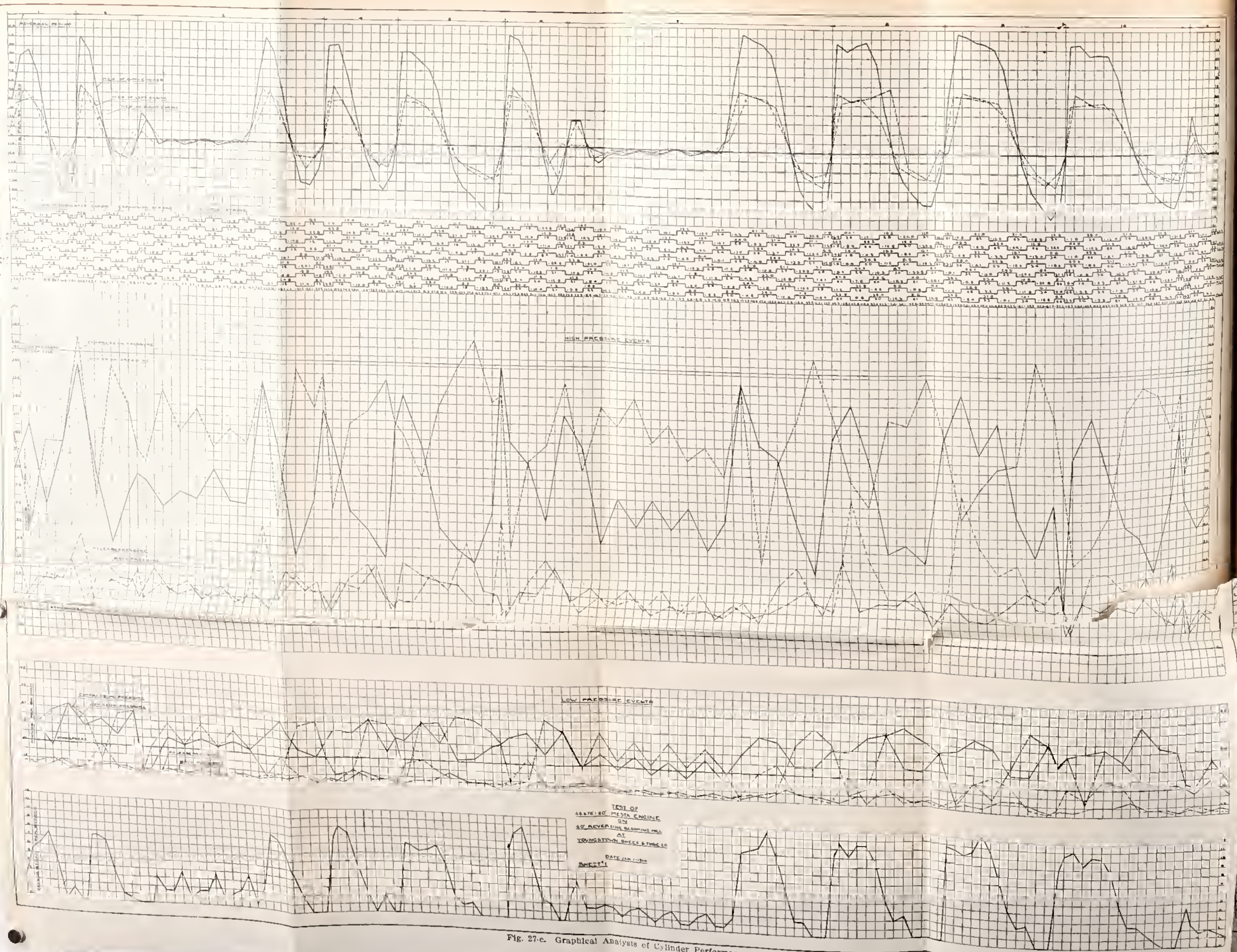

Fig. 27-c. Graphical Analysis of Cylinder Performance. (Part 1).

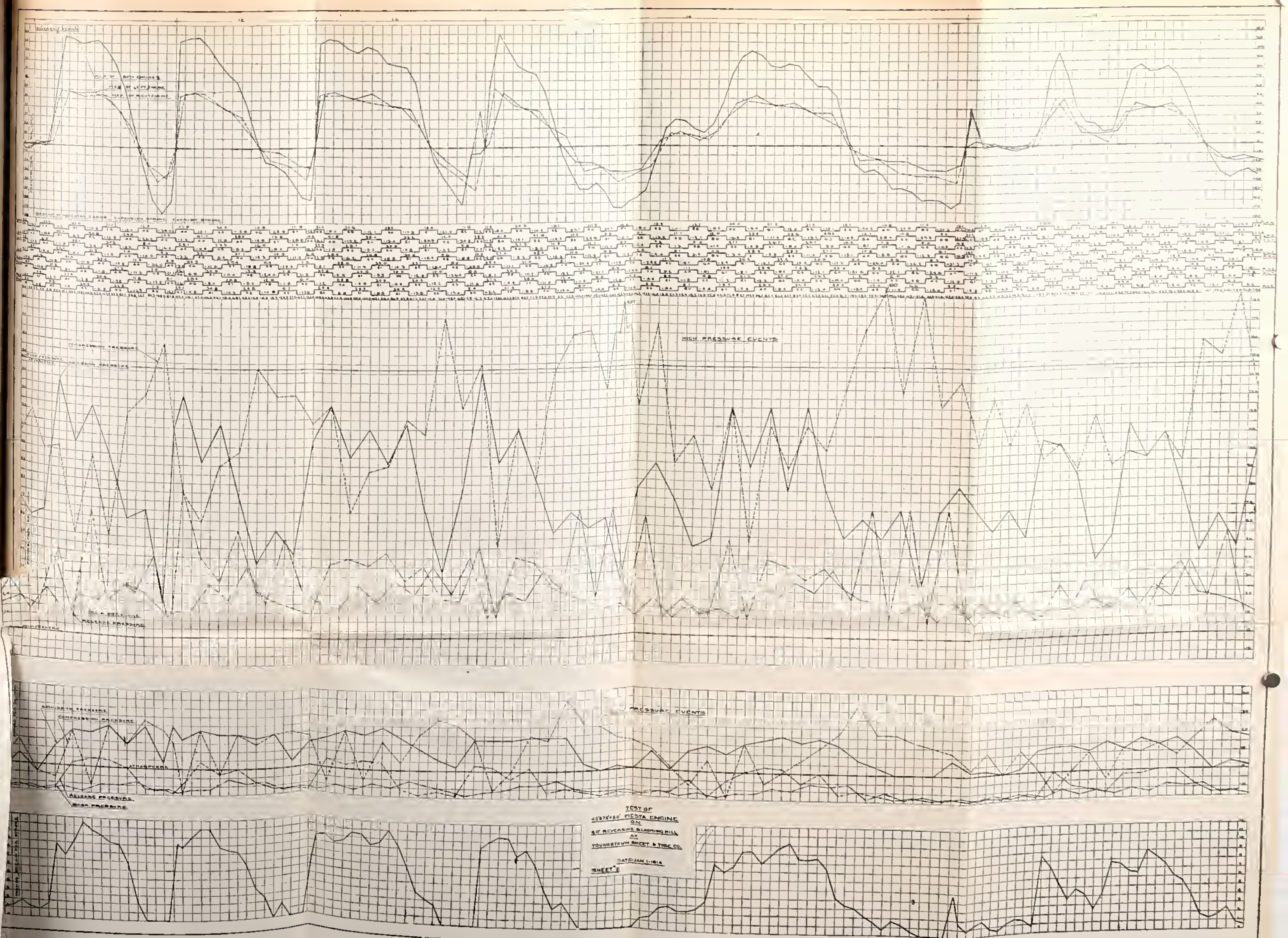

Fig. 27-d. Graphical Analysis of Cylinder Performance. (Part 2).

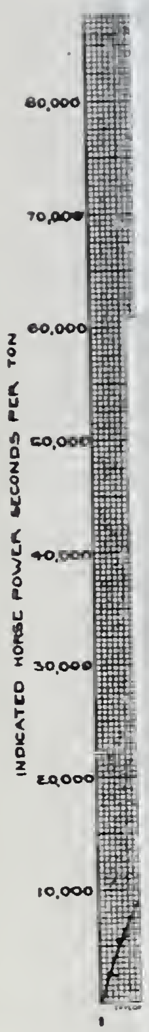
INDICATED HORSE POWER SECONDS PER TON
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000

Fig.
of I
No.

As the figures shown in Tables No. 1, 2, and 3 compare quite closely with those shown in Tables No. 6 and 7, and Tables No. 8, 9 and 10, we feel that the results of the operation of this mill have been sufficiently checked and can be taken as representative of the operation.

Table No. 10. Summary of Results as Calculated by H. C. Siebert from Tests No. 7 and No. 15.

Set Number	7	15
Weight of Ingot—Tons	2.74	2.46
Length of Ingot—Ft. & Ins.	4 ft. 9 5/16 in.	4 ft. 2 13/16 in.
Average area of Ingot—Sq. Ins.	379	399
Section of Bloom—Ins.	4⅞ in. × 6¾ in.	7 in. × 5⅛ in.
Area of Bloom—Sq. Ins.	32.9	35.9
Length of Bloom—Ft. & Ins.	55 ft. 0 in.	47 ft. 0 in.
Elongations	11.52	11.10
Indicated Work—H. P. Secs	211,106	206,113
Friction Work—H. P. Secs	37,465	33,690
Acceleration Loss—H. P. Secs.	61,901	77,014
Available for Rolling—H. P. Secs	111,740	95,409
Friction Work—Percent	17.8	16.4
Acceleration Loss—Percent	29.3	37.3
Available for Rolling—Percent	52.9	46.3
Total Steam—Pounds	1,302	1,272
Steam per Ton for 11 Elongations—Pounds	475	515
Steam per I. H. P. Hour (Dry from Ind. Cards.)—Lbs.	17.1	17.1
Steam per I. H. P. Hour (Plus 30% for losses)—Lbs.	22.2	22.2
Temperature—Deg. F.	2,245	2,200

The writer wishes to express his appreciation of the valuable assistance of all of the members of the Steam Engineering Department of The Youngstown Sheet & Tube Company, and especially to Messrs. Kneass and Butler who have devoted much of their time to the calculation of results and preparation of curves for this paper. He also wishes to thank Mr. H. C. Siebert, Mr. W. C. Coryell, and the Mesta Machine Company for their calculation of separate ingots for the purpose of checking the results obtained by the writer.

DISCUSSION

Mr. Charles Fitzgerald, Jr.*: Mr. Nibecker's paper is highly interesting and valuable for several reasons, among which may be especially noted, the unusually low values obtained for steam consumption per I. H. P. hour. Although the results obtained for the economy of the engine are exceptionally good,

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other features of the engine have counteracted this apparent economy, resulting in a steam consumption per unit of effect on the steel that is not record-breaking, though as good as the best engines built previously.

The only exception that can be taken to the test methods is the marking of ½ seconds points on the indicator paper for the purpose of plotting a speed curve, since the instantaneous linear speed of the paper is proportional neither to time nor to the speed of the engine. Only a very approximate curve can be plotted in this manner, interesting to show the general shape, but not valuable as a means of applying a kinetic energy factor to the solution of the problem of actual force applied at rolls. The location of the passes by this method is also open to error unless checked by the indications of a correct speed curve, which shows plainly the period of the bloom in the rolls. This fact is illustrated on one of the figures where a pass mark is shown overlapping a reversal point.

Mr. Nibecker states that "it is assumed that the work consumed in stopping the rotating and reciprocating parts is the same as that consumed in accelerating them." This need not be considered an assumption as it is a physical fact.

The impossibility of using a large amount of steam in plugging this engine is not apparent. The amount of steam lost in this way is proportional to the size of negative cards preceding reversals, which owing to the excessive inertia, are larger than on other engines of the same type. The quantity of steam lost in plugging the engine is not of great importance and has not been considered on tests of this kind. The check on steam consumption made by means of a weir and recording thermometers is open to a considerable element of doubt owing to the failure of the thermometers to follow the rapid variations in temperature of condenser water occurring in this class of service.

The figure of 18 pounds per I. H. P. hour looks too good to be true. This unit is a function of the shape of the indicator card, and the fact in the case is, that the best individual cards from this engine do not show as good expansion as the average cards from a Corliss compound engine driving a three-high blooming mill. With this fact in view, therefore, the

economy of an engine of the later type should be very much lower than the figures generally accepted. However, comparisons of this kind should not be made unless the operating conditions in both cases are known and stated.

The gap between the economy of the Mesta engine and those using throttle control is widened by quoting the figure of 35 pounds per I. H. P. hour, which is too high. With the same vacuum and allowance for moisture as considered in arriving at the figure of 18 pounds, the throttle controlled engine would not exceed 27 pounds. Notwithstanding this fact, the difference shown in favor of the single lever control is very striking. An error has probably been made in quoting a friction loss of only 9.8 percent. This figure should be from 17 to 20 percent and this difference must be subtracted from the percent of work available for rolling, bringing the latter figure down to about 46 percent.

The curves of work, Figs. 17 and 18, will be misleading if they are considered in any way as indicative of the engine operation. They express functions of mill operation and steel conditions only. To obtain curves of the actual work supplied, the indicated work must be plotted on the same basis, and due to the excessive amount of acceleration loss, these curves will be found higher than those of any other similar engine yet tested. It is because of this fact that while the steam consumption per I. H. P. hour is very good, yet the steam per unit of effect is no better than that obtained in other good engines.

However, when the causes of this excessive loss are removed, there is no doubt that engines of this type will become an efficient substitute for one of the most inefficient machines in modern steel works practice.

THE AUTHOR: At the time of making the test which the leading paper described, it was our custom to place the half second indications on the indicator card. This we realized at the time was not the best method of procedure, but was used in the absence of a better scheme. It is our practice at present to locate these points on the constant speed chart of the Hallwachs steam meter recorder.

When the seconds are recorded on the indicator cards, we

fully appreciate that the indications cannot be used as plotted, as the cross head, and hence the indicator moves at a varying rate of speed. These, however, bear a certain ratio at every instant to the velocity of the crank and hence the rotation of the engine. By means of a small crank and connecting rod diagram, these points can readily be referred to the condition of uniform speed, so that an accurate representation of the curve can be plotted.

As regards the friction load upon this engine, we feel that there are slight possibilities of making an error in this determination. As mentioned, this quantity was determined from a large number of continuous indicator cards taken with the engine running at constant speed. In order to demonstrate that this is not an impossible value, we would refer to the engine at the Brier Hill Steel Company,—the results of a test of which are appended to this paper.

The friction M. E. P. of 5.5 and a friction work of 13 percent which was determined from this engine, will be found to be considerably below the 17 to 20 percent as mentioned by Mr. Fitzgerald as being the proper amount. Both the Brier Hill engine and the Youngstown Sheet & Tube engine are much more modern than the engines with which Mr. Fitzgerald is familiar, and it must not be thought impossible that these new and highly developed engines should have a friction horse power lower than any of those to which Mr. Fitzgerald is accustomed.

It will be remembered that in the original paper, the check of steam consumption by means of the condenser heat balance was given only as a matter of interest. We feel that it is quite remarkable that this value should check as closely as it does with the proper value when the difficulty of obtaining the necessary observations is considered. We do not advocate the use of this method except as a very poor and rough determination in the absence of the necessary steam meter, and would only accept the results thus obtained as approximate, after every possible precaution in determining the observations had been applied.

Mr. M. F. McConnell*: I wish to express my appreciation and thanks to the writer of this paper. Any one who

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has handled much of this work will understand the tremendous amount of detail required in preparing such a paper for presentation.

We have no reason to question that the data offered is correctly reduced from the indicator diagrams as taken and is a proper record of the power and steam consumption during the rolling. While the steam consumption per indicated horse power as reported is truly remarkable for a reversing engine, it is not exceptional when compared with ordinary engine practice and is hardly more than ordinary when considered on a basis of work actually delivered to the rolls.

As far as I can see his work, his tests and methods of tabulating have been very accurate and I haven't any reason to doubt anything his test data has shown. The only question that comes up is one of interpretation of the tests as shown. The question of a steam consumption has been raised by Mr. Fitzgerald, that is, that the actual appearance of the indicator cards does not seem to justify a steam consumption as low as that which he has shown. In fact, it takes a pretty nice looking indicator card to show a steam consumption as low as 20 lb. when you make an allowance of 6 lb. for condensation.

One remarkable thing is the high vacuum which he reports in his low pressure cylinders, 25 in. when we consider the speed at which this engine runs a good deal of the time. I am not expecting normally a low pressure indicator card showing a vacuum of 20 in. or 22 in. even in slow speed work.

Mr. Fitzgerald has brought up the question of comparison with a three high mill engine for steam consumption I do not think that that need be brought into the matter because a two high and a three high mill are almost entirely different. The work which is laid out for the two high mill in the Youngstown Sheet & Tube Co. plant, shown by Mr. Nibecker, is entirely out of the proper range of the three high mill. It seems to me there is a very small field where the matter should be considered.

Mr. Nibecker showed a curve in Fig. 18 to which I would call attention, as it adds to the discussion that was raised at the

time Mr. Siebert's paper was presented,* the question of the units by which the work of the rolling should be measured. In this case he brings out the work for elongation. At the time of Mr. Siebert's paper we suggested the formula which has been used. Mr. Edwards, of the Morgan Engineering Co., brought out at that time a formula where he has a certain constant times the logarithm of the ratio of reduction and elongation. I have undertaken to analyze the curve which Mr. Nibecker has shown.

The accompanying Fig. 28 shows the power curves of this test, the gross work curve D showing the total energy expended per elongation. The gross less friction, curve E, shows the work expended above that simply required to turn the engine over. The net work, curve J, shows the work which actually reaches the mill after deducting the work required for acceleration. The difference between these last curves shows the tremendous price that has been paid for the increased steam efficiency.

For the purpose of comparison, I have plotted the data from the test published by our fellow member, Mr. F. G. Gasche, in "Power", June, 1907; which shows a comparative check with the net curve of the test under discussion. As far as I know, no effort was made in Mr. Gasche's test to eliminate the work of acceleration.

Curve G is the logarithmic curve of the formula:

$$W = \text{Hyp. Log. of } R \times C$$

when $R = \text{Number of Elongations}$

the coefficient $C = 11\,000\,000$ foot pounds.

The similarity of this curve to that shown by the two tests plotted and borne out by many tests in which the writer has been interested, is sufficient evidence to me that having developed the coefficient C for any given set of conditions, such as temperature, density of material and general rolling conditions; the formulae will give results for the whole or any subdivision of a rolling problem, the accuracy of which will be well within the allowances which we are bound to make for variable conditions in the operation of any mill.

*"*Measurement and Calculation of the Power Required to Roll Steel*", by H. C. Siebert and Charles Fitzgerald, Jr.; Proceedings, Engineers' Society of Western Pennsylvania, 1913, Vol. 29, p. 445-567.

We all realize that this coefficient will become greater on the smaller sections, such as sheet bar, skelp and bar mill products. A large portion of the increase may be credited to the greater mill friction as compared with the work actually done on the steel.

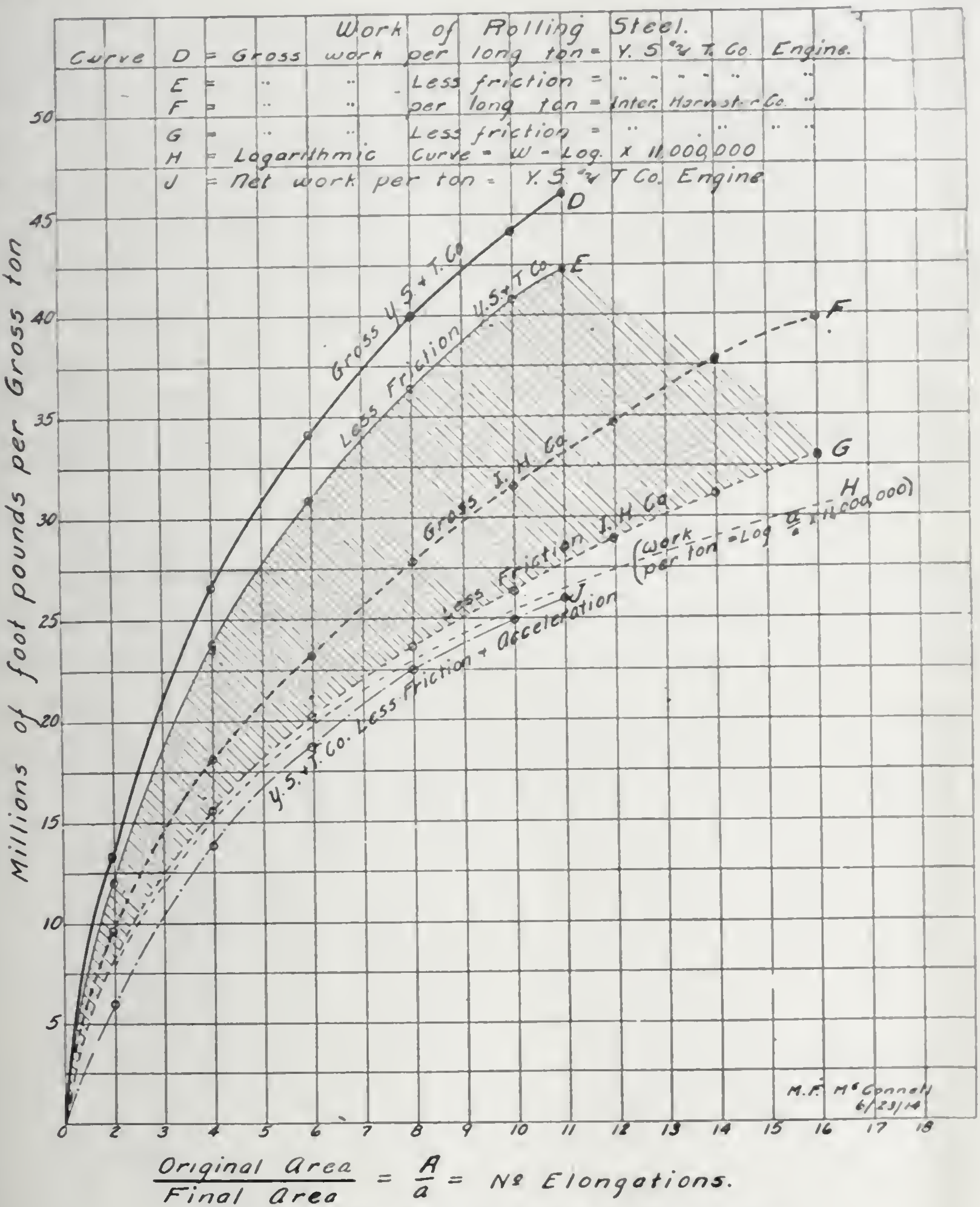

Fig. 28. Work per Unit of Elongation.

The value of 12 030 000 lb. for Mr. Nibecker's curve compares very favorably with any other testing which I have noted, where the value of friction has been eliminated from the calculation. That value of friction he gives at about 10 percent. We usually found it running from 15 to 25 percent.

The last column in Table No. 1, is the column Mr. Nibecker used to plot the curve which we last showed on the screen, and our formula will work about to that constant of 12 000 000. If you use the constant of actual work shown in the fifth column, you will find 90 800 837. That will give you a constant of about 19 000 000.

I have compared this with the different tests published by Dr. Püppe and one test published by Mr. Gasche in 1907. I find that instead of 19 000 000 on this engine, the Gasche test runs about 17 000 000 or 16 500 000; but it shows an excess of 10 to 15 or may be 20 percent, for the work actually being done by this engine to roll a given amount of steel, over almost any other published tests for lighter engines in this service. There have been no tests published on the heavier engines such as Mackintosh-Hemphill engines at Duquesne, Aliquippa or Midland. I do not know how they will compare with this engine.

I might call attention to another curve, the one that shows the amount of work per cubic inch of displacement, Figure 17. That is the other unit which has been submitted as the basis. That unit is all right when used under the conditions where they have used it, that is, adding the number of cubic inches. If you pass on and accumulate that up to the end, it results in a peculiar condition in having displaced 33 000 cubic inches of an actual volume of 15 000, which means that the same cubic inch has been displaced at least twice, if not more. It would also seem that if we undertake to take the actual reduction of the piece during the rolling, which in this case represents a reduction of about 90 percent, we would only have about 13 000 cubic inches displaced and we would have an entirely different result than the average shown by the actual curve. This line follows almost identically the line which you would show if you would plot the steam consumption and the work done per unit of reduction as the hyperbolic logarithm of the number of elongations.

The real and serious question brought out by this test is: Can we not design an engine for this service that will give reasonably good steam consumption, without adding such a tremendous burden of wasted energy?

The Author: In regard to Mr. McConnell's discussion, he says a steam consumption of 20 lb. is rather remarkable even in a Corliss engine. We should take into consideration that this engine runs most of the time at better than 145 lb. steam pressure, and we have constantly better than 28 in. vacuum in the condenser, giving us from 25 in. to 20 in. in the cylinder of the engine. If the efficiency is worked out on the Rankine cycle, you will find it not abnormally high.

I am very glad that Mr. McConnell has brought out the question of obtaining the unit of work by the hyperbolic logarithm of the elongation, and I am very much pleased to find that the constants that apply to that formula of 12 000 000 seem to check at least in a sort of a way with Mr. Gasche's figures.

Mr. M. F. McConnell: It checks with most anything in that line that I have been able to find. Of course, it was worked up without consideration of friction losses.

The Author: I think their discrepancy could be explained by the amount of power used in acceleration and retardation and the low friction.

Mr. C. A. McCollum*: In rolling steel, as in many other operations, we desire the most useful work for the least cost. The steam consumption reported in this paper is about 30 percent lower than we are accustomed to for this class of work. I sincerely hope that such is the case and that no mistake has been made, as it indicates that the steam engine has not reached its fullest development for rolling mill work.

A test of this kind requires much care in preparation, conduction and calculation. The most important phases of these operations have been previously discussed, but a few additional remarks may be made. It is very interesting to note the rapidity of reversals in such a large engine, but I do not believe a half-second's time recorder is accurate enough for determining acceleration forces where the speed changes from 60 r. p. m. in one direction to 30 r. p. m. in the opposite direction in 2½ seconds. This is equivalent to a rate of change in

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speed of 14 r. p. m. in ½ second. Closer time recorders can easily be obtained by the various pendulum arrangements.

Our experience with the Hallwachs steam meter has shown it to be very sensitive to fluctuations such as obtain in a line supplying a large reversing engine. For friction loads and light passes, however, this meter reads too low, partly on account of the greater distance between platinum contacts near the bottom of the manometer.

Another item of interest, and also of importance, is the temperature of the steel being rolled. I have seen some tests reported with a uniform decrease and some reported with a uniform increase in temperature. Mr. Nibecker has it both ways and finished with the piece 81 deg. Fahr. hotter at the end of the fifteenth pass than it was after the first pass. We have found that the temperature obtained during rolling does not depend nearly so much on the condition of the steel as it does on the method and judgment used in obtaining them. For the sake of comparison, it would be well to have a standard method of obtaining these temperatures, since the work required and steam consumption per ton rolled is less with hot than with cold steel.

The reading of this paper directs us again to the subject of "Standardization of Tests on Rolling Mills". It is to be regretted that, in the World's Steel Center, such a quantity of useless data (useless for actual comparison) has been collected and reported in whatsoever form the individual in charge sees fit to submit it. Would it be within the province of this Society to appoint a committee whose duty would be to suggest methods of conducting tests on the leading types of mills?

The Author: As regards the criticism raised by Mr. McCollum that the steam meter will not read properly on small amounts of steam, we would say that the type of meter which we use is so constructed that the contact points at the bottom of the manometer are spaced more closely together, thus making the instrument accurate,—even on light loads.

The author quite agrees that a committee upon standardization of mill tests would be of much value and the data obtained could thus be made of infinitely more real value to those interested in this most important subject.

MR. JULIAN KENNEDY*: I got this paper late last evening and read it this forenoon so I have not had a great deal of time to go over it. I want to take up one or two features.

There has been a criticism of high counterbalancing of this engine. Now the place where this engine goes as you know, is a place where the ground is not particularly good, where there has been another engine running balanced about as well as the average, and yet which shakes the entire plant. You know there are locations of that kind. And it is more important sometimes to get things that will not shake the plant down than it is to save the last pound of steam per ton of steel.

You are also all acquainted with the type of engine which is very light in rotating parts and somewhat moderate in its cylinder power which goes off after this fashion (illustrating). When the ingot goes through it speeds up to 200 r. p. m. and then it stops. Of course, they do not use very much power in accelerating, but it does use up a good deal of power and smashes a good deal of machinery in other ways, and you never see a pinion run six years without touching with an engine of that kind hitched to it, and you never find a set of spindles run six years without breaking and being thrown away with an engine of that type. It may show more power put into the mill in proportion to the indicated horsepower than another type of engine. So would any rolling mill engine if you took the fly wheel off of it. But it would not roll steel successfully. It would smash the mill and the steam consumption would go away up.

We say that steam consumption is improved a great deal by using short cut off and reversing engines. So it is. There is no doubt about that. If you could eliminate from that engine features which make a short cut off possible and save some other percentage, of course you would get a phenomenal result, but you cannot eat your cake and have it too.

There is another thing you noticed in going over the tables. In some passes the amount which was represented by plugging the engine at the end was about 15 percent of the work done during the rolling of the ingot. In the next pass we found it running 40 percent and no apparent reason for it at all. You

*Engineer, Pittsburgh, Pa.

will find that one man will average 10 percent better than the other in his steam consumption in the mill. There would not be any material loss but that engine would be shut down at the right time so that the engine running 145 in the middle of the ingot would come down to about 30 as the ingot leaves the roll. And that will be done a little later. The gear on that engine is a new gear and very sensitive and like some other things you push it and you have got to jiggle it back. Since they have had some experience with it they have developed the ingenious device of putting a spring at the far end so that the man pushes the handle and it pushes it back. That helps the man handle it more accurately, taking out the lost motion, so the control is very much better and I have no doubt at all that today the best man that runs that engine can show under 20 percent instead of 34 percent.

The Author: I think so, yes.

Mr. Julian Kennedy: And a little later you will get it down to 15 percent. Now what you want in a mill is not particularly the very lowest steam consumption per indicated horse power, but you want fairly low consumption per ton of steel and a nice smooth running mill that will run a long time without repairs and one that you do not have to get at every Sunday, taking up slack. One can easily imagine the relative effect of a mill of jumping it along irregularly or running it as smoothly as any electric motor would run it.

In regard to the reciprocating parts of this engine, it was understood that the reciprocating parts should be light, and Mr. Iverson who designed this engine got those parts as light as was considered conservative, not to the very last notch because we did not want to get an engine like a racing automobile, but one which would be reasonably light and at the same time strong and reliable. Then came up the question of counterbalancing. It would be very easy to get a very thorough test on the engine that we have been hearing about on counterbalancing. The counterbalance weights are put on in such a way that it would be a small job to remove them. If a lighter balance weight or lighter rotating parts would help steam consumption, it is the easiest matter in the world to get them off. But remember

when you take them off, instead of the pressure on your main bearings which tends to shake your blast furnaces, stoves and other structures, (and 292 tons about is the maximum pressure on the two main bearings of the engine running at 200 r. p. m. which is about the speed we have to provide for) with counterbalances removed, it is 982 tons. Quite a little difference on a bed of blue clay.

The bending moment on the crank pin at the end of the pin where it joins the check is 7923 inch-tons. With those counter weights off it is 16 203. It makes a difference between a 25 in. shaft and a 28 in. shaft if you want corresponding strength. The shaft was cut from 28 to 25 and possibly it should have been cut below 25, but the makers felt it would look as though we were skinning the job if they cut it that much and, therefore, did not go to the limit of what might have been done, possibly with advantage to the engine. The counterbalances on each engine are equivalent to 40 600 lb. The other rotating parts in the system bring up the total rotating weights to 245 000. Some of that the designers are not responsible for. It was necessary to build that mill to roll a pass through on a slab 4 in. thick and the next time to edge a slab 42 in. wide, therefore they put on large pinions and long spindles, etc. The rotating masses on the shaft are balanced, in addition 55 percent of the reciprocating parts are balanced. The consequence is that the engine does not shake the plant. Under some conditions I know of it would be the wise thing to do to put on more counterbalance. Several years ago, the writer installed an engine running 250 r. p. m., 20 in. stroke, at the top of a hoist at the Lucy Furnace. That engine was balanced 100 percent on the reciprocating parts set 100 ft. from the ground on a hoist tower and it does not shake at all. It was tested sitting on gas pipe rollers without any motion. It is easy to do that.

Now all that is necessary to get that work back is to learn to shut the throttle at such time that it will bring the engine down to 30 revolutions as the piece leaves the rolls. That will give quick enough reversing for anything but the most rapid work. You must remember that a great many of the engines of this country have just as good valve gear as this engine, floating gears and everything to permit the nicest arrangement

of cut off. A great many reversing engines would not run comfortably with a cut off because they haven't quite enough weight in rotating parts. You cannot run an engine with 25 percent cut off without a little bit of fly wheel, and if it takes a little power to handle that fly wheel, you had better have it and save a greater amount of power by using a cut off.

Mr. H. C. Siebert*: Mr. McConnell states that the cu. in. displaced in the different passes when added together result in the peculiar condition of having a displacement that is greater than the volume of the original body. I wish to state that there is nothing peculiar about it. It is a fact. The reason why the displacement varies with different drafts and number of passes, also the difference in the displacement as obtained by the formula recommended by Mr. McConnell and the formula used by Mr. Nibecker, already has been fully discussed before this Society, and it is unnecessary to go over that ground again.

Those who will study the two formulae with the aid of the discussion as found in these Proceedings Vol. 29, November 1913, p. 545 etc., will have no difficulty in dispelling apparent peculiarities. It may be restated here, however, that the volume displaced according to the Hyp. log formula recommended by Mr. McConnell is always greater than that calculated by the formula that was used by Mr. Nibecker. Besides, the former formula disregards the equality between the volume displaced and the elongation while the latter formula takes this equality into account. This fact is important and is very clearly shown on the table on p. 550 of the Proceedings above referred to.

It can be stated also that in the hyp. log formula as soon as $\frac{A}{a}$ becomes 1 or greater than 1, the volume displaced will be equal to or greater than the volume of the ingot. Thus, for example, if we have a reduction of area of 63 percent in one pass, we will displace 100 percent of the volume of the body being rolled. This may seem like an extreme reduction, but it serves to show the fallacy of the Hyp. log formula. I am satisfied that Mr. Nibecker has followed the logical processes by basing his results on displacement of the formula $Vd = (A - a) L$.

*Steam Engineer, Duquesne Works, Carnegie Steel Company, Duquesne, Pa.

Prof. C. L. W. Trinks*: In this discussion, I should like to make first a few remarks in reply to Mr. Fitzgerald. He states that the engine and mill friction should be higher than taken in Mr. Nibecker's calculations, because he invariably found it to be higher. But Mr. Nibecker has taken a great number of friction cards, and I think that we can believe the indicator cards in this instance. The fact that Mr. Fitzgerald is exceedingly well acquainted with engines having greater friction does not mean that the engine under discussion must have the same amount of friction. From my knowledge of the present engine and of the majority of other engines, I should judge that it must have less friction. There is a stream of oil running on all the bearings, the hollow shaft is full of oil and lubricates the crank pins. The eccentrics are flooded, etc. There is a great difference between stream lubrication and drip lubrication. Perhaps we should be more definite in our expression of percentages and should state whether we mean percent of total positive work done or percent of work going to the mill.

Finally I have my doubts about the degree of accuracy of steam flow meter under heavy fluctuations. They must be damped in order to prevent excessive natural vibrations of the mercury column. From the fact that the mercury indicates the square of the velocity, results the conclusion that damping makes the meter read too high. Take for instance, a velocity of flow drawing abruptly and cyclically from 6 to 10 feet per second and back again. If the meter is so well damped that it shows the average, it will show $\sqrt{100 \div 2}$ or 7 ft. per second; whereas the time average is 5 ft. per second. This example is an extreme case, but it shows the tendency.

Mr. McConnell stated that in his opinion, twenty pounds per indicated horsepower hour was a pretty good steam consumption for a continuous running compound condensing rolling mill engine, and that thirty pounds was good for a non-condensing engine. I would like to have Mr. McConnell come out to the Carnegie Institute of Technology some evening where he will see a single cylinder non-condensing engine operating on 17 to 18 lb. per i. h. p. hr.

*Professor of Mechanical Engineering, Carnegie Institute of Technology, Pittsburgh.

I also wish to answer the remark made here by some one that the temperature of the steel apparently rose during rolling. All who have made tests of this kind have observed the same phenomenon. The temperature in reality does not rise, but the pyrometer sees at first the cool outside of the ingot instead of its warm inside. After a few passes you get the inside out, so to speak, and that, of course, causes the apparent temperature rise. If you look over Dr. Puppe's book of mill tests, you will find the same apparent temperature rise in every case.

Instead of discussing the paper further, I wish to say a few words on the history of the compound reversing engine in this country. I believe I can speak with some authority on this subject, because I have been connected with it from the very beginning.

The first twin tandem compound reversing engine that amounted to anything in this country is running at the present time at the Cambria Steel Co. I was present when it was designed and built by the Southwark Foundry in Philadelphia in 1899 and 1900. However, this engine did not carry the country by storm.

Being convinced of the value of this type of engine, I tried to convince others of its value, while I was chief engineer of the Wm. Tod Co. of Youngstown, O. My chances appeared very thin, until the Illinois Steel Co. (where the progressive Mr. Gasche has something to say), bought two of these engines. I had the pleasure of designing these engines and of reporting on them to this Society in 1905. They struck a warm spot in the heart of the American rolling mill engineer with the result that within the following year seven or eight others were built.

Now, it is a general rule that anything that is a commercial success is followed, imitated, copied or improved upon by others, whatever you wish to call it. But it also happens that by some only the external features are followed and that hidden features, such as port cutting in throttle valves, etc. are missed. The consequence was that some of these compound engines can scarcely be called a credit to the art of the engine builder and did more harm than good as far as their general introduction is concerned.

About that time the exhaust steam turbine came along. It

seemed to sound the death knell to the compound reversing engine, because the standard American simple reversing engine exhausting into a steam turbine was certainly simpler and more economical than some of the so-called compound reversing engines. I know of two cases where the combination engine and turbine were installed for that reason.

The building of the engine under discussion was occasioned by the unsatisfactory operation of a regenerator plant. I take great interest in the paper of the evening, because I did my best to have this engine equipped with the single lever control which has been so successful in Germany. There it is even more successful than it is on the engine under discussion, because there we find three crank, six cylinder, compound reversing engines. If we tried to introduce a six cylinder engine in America at the present time, we would meet with considerable resistance on the part of the master mechanics who feel that it is hard enough to look after four cylinders and that it would be too troublesome to look after six. I believe that they will realize that, with engines of the type under discussion, four cylinders are no trouble at all and that engines can probably be so built that six cylinders occasion no more trouble.

In my experience I have found that there is a great deal of British conservatism in the American rolling mill engineer and master mechanic. When I designed the engines for the Illinois Steel Co., I succeeded in breaking down some of the old rules, but in other "radical innovations" I did not succeed. For instance, I tried to equip the engines with short main bearings and with a simple straight line valve gear in which the rods took hold of the valve eccentric. No use; under pressure of the engineers from the Steel Company and of my colleagues at the engine works, I had to make main bearings long enough to carry a 200 ton fly wheel when there was no fly wheel to be carried, and I had to build a round-about valve gear, because it "would be very unmechanical and poor engineering" to take hold of the valves out of the center. I am more than pleased to report that the engine under discussion tonight has short bearings and a straight line valve gear drive. And I am somewhat afraid also, if it had not been for the fact that Mr. Julian Kennedy was consulting engineer for the Youngstown Sheet

& Tube Co. on this engine, it might have had long bearings also. I think that the rolling mill industry is indebted to Mr. Kennedy for breaking down some of the superstititions existing in it.

Having been connected in the reversing engine industry for so long, I naturally have ideas as to what a good reversing engine should really be. If I should lay these before you, I would probably be called an utopian, a dreamer, or one of those theoretical, impracticable professors. And yet I hope to have the privilege of reporting to you again eight or ten years from now and I feel certain that at least some of my "dreams" will have been realized at that time.

The Author: As regards the steam flow meter, it must be borne in mind that the meter does not register average steam flow, due to being properly dampened, as suggested by Prof. Trinks. The only part of the meter affected by inertia, is the small mercury column.

The steam flow at every instant is recorded by means of a dead beat electric arc recorder and the quantity over any given time is obtained either from the recording chart, or by means of a delicate recording wattmeter controlled electrically by means of the mercury column. When these facts are considered, it will be seen that the meter is reasonably accurate.

Mr. H. C. Siebert: I would like to make an answer to the point brought out by Prof. Trinks in regard to the friction loss of 17 to 20 percent.

We have had considerable experience in testing reversing engines of different types, some half dozen of them. Only one of these machines, a small simple engine and an old engine, did not have forced lubrication at the time of testing. All the others had. I found that the friction load from the reciprocating and all rotating parts, referred to the engine journals amounted to between 9 and 10 percent of the total weight of moving parts. In the case of the Mesta engine there was just 2 percent difference, that is the Mesta engine showed about 2 percent less than the others. However, the criticism of Mr. Nibecker's 9.8 percent for friction loss was not based on a comparison with other engines, but on a calculation using the friction cards referred to by Prof. Trinks. Mr. Fitzgerald is not here at present, but I

believe I can defend him on that point, that he was fully justified in criticising the low figure given for friction by Mr. Nibecker.

Mr. J. C. Hobbs*: May I ask Mr. Nibecker what method was used in determining the calibration constant of the steam flow meter.

The Author: We used the throttling disc and the area of the disc was measured and the difference of pressure determined by the mercury column which was attached to the meter, and from that the amount of steam which should pass through that orifice with that difference in pressure was calculated and found to check with the calibration of the instrument as furnished by the maker. It was not checked by any absolute measurement. It was impossible to do that with the amount of steam we had to use.

Mr. J. C. Hobbs: I found as much as 25 percent difference in calibration valuation in a constant flow and reciprocating flow in meters of the same make.

The Author: The makers of these instruments have furnished two constants, one applying to constant flow and the other applying to variable flow. The two constants furnished by them I have also checked up with the constants as given to me by one or two other makers of meters and I found that it is possible to determine them within a few percent even with variable flow if you take the amount of pressure difference shown by the fluctuating load.

Mr. J. C. Hobbs: I can agree with Mr. Nibecker on the first point. When I purchased the first Hallwachs meter of this type in this district, the makers of this particular meter furnished me with two sets of constants, each worked out to be correct (?) within one part in ten thousand. These two sets only varied by twenty-five percent. After a long study of every commercial type of meter which is available, I have yet to find any one who can correctly predict, forecast or calculate the constant which should be used on anything except a constant flow.

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The correction for pressure is extremely simple and is very nearly proportional to the density of the steam, but the constant for use on a reciprocating flow depends upon several variables; the most important of which is the shape or form of the flow wave.

This is probably best explained by referring to the simple equation $V = \sqrt{2gh}$, which is the basis of practically all steam flow meters of the velocity type.

Adapting this to steam meter work, we have $W = K \sqrt{h}$ where

W = weight flowing in unit time

h = pressure difference between the leading and trailing pressure connections and

K = a constant which varies with the following factors:

(a) Steam density (determined by pressure and temperature)

(b) Diameter of the orifice in the throttle disc.

(c) Ratio of the diameters of the pipe to the throat area of the throttle disc (b).

(d) Form of the flow wave.

due respect to the units involved being observed.

When the flow is steady it is simple, but when the flow is variable many complications arise.

The inertia of the instrument will allow the mercury column to follow only those changes which have an appreciable time duration. The charts show the flow to vary through the various passes, but there are no meters which can show the variation which actually takes place during the various parts of one stroke. This is essential since there is a great difference between the mean average of the square root of the instantaneous pressure differences and the square root of the mean average of the pressure differences. When these are calculated (most easily done by integral calculus) for the mathematical curves which approximate the actual curves, the wide variation is confirmed.

Due to the receiver passages as well as receivers which are installed as receivers or separators, the actual variation is not as great as the calculated results would indicate.

THE AUTHOR: Mr. Siebert, what can you tell us about that?

MR. H. C. SIEBERT: The amount of steam required by such a large engine precludes any method of direct calibration unless a surface condenser is available. We tried to calibrate a disc by the surface condenser method on a small twin reversing engine, 8 inch cylinder diameter by 10 inch stroke, running up to 200 r. p. m. The cycle of service of this engine is similar to that of reversing blooming mills.

Notwithstanding that the surface of this condenser was very liberal, we found that we were able only to condense a very small portion of the total steam used. This method of calibration was therefore abandoned and we made a jet condenser. This consisted of a wooden box about 3 feet wide, 4 feet high and 7 feet long, provided with necessary baffles, water inlet, outlet and overflow. This box was filled with cold water to about 12 in. of the top (to the overflow), steam permitted to flow in until water became heated to about 140 deg. Fahr. when steam was shut off and the water above overflow (condensed steam) drained off and weighed. Of course, steam meter charts were taken while steam was exhausted into condenser. By this means we calibrated different sized discs under variable pulsating flow and under uniform flow of steam. The results of these tests showed that while under certain conditions of service the constants furnished by the instrument makers are correct, they are not invariably so, as in some cases the meter was found to read low by as much as 20 percent, and high by as much as 25 percent. The former figure depending upon the size of disc used for a given flow, i. e., the deflection of the mercury column in the manometer, and the latter figure depending upon the number of pulsations per minute. In fact, we found a number of variables that influence the accuracy of the meter, the chart of which cannot be properly interpreted except through knowledge of these variables.

THE AUTHOR: Replying to Mr. Hobbs' discussion, I would say that we have never calibrated this meter, as the quantities of steam handled are very large. The difficulty, as well as expense of making such a calibration under any conditions

approximating those on which the apparatus shows, will be readily appreciated by any one who has undertaken such a task. We would refer to the discussion by Mr. Siebert for such work as has been done along this line.

The constants used by him for the meter were those furnished for variable flows, which when properly determined, as explained by Mr. Siebert in his discussion, can be checked in a miniature apparatus. We, therefore, believe that the reading of the meter was reasonably accurate.

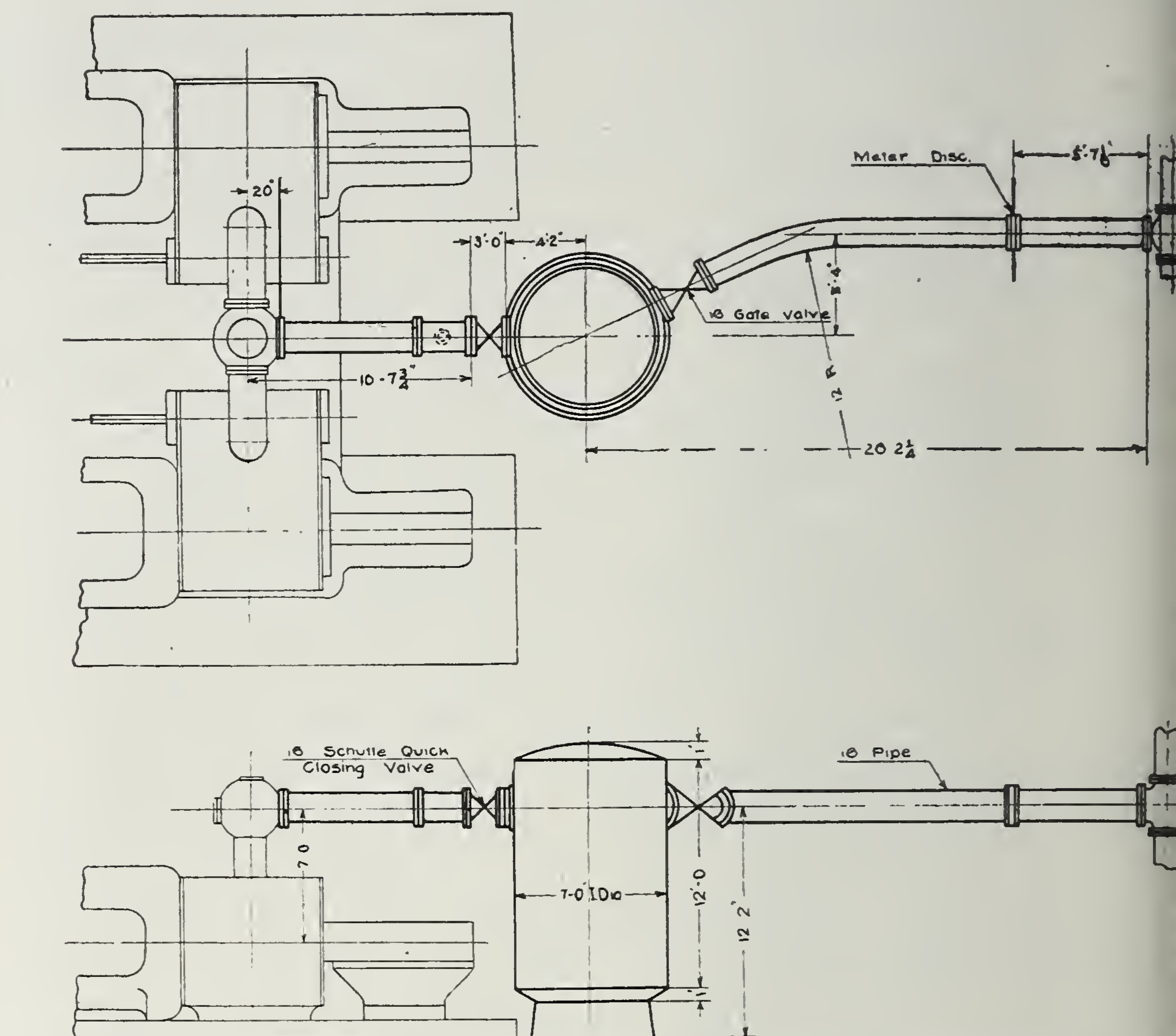

Fig. 29. Steam Piping and Receiver Separator Arrangement.

It is conceded that the meter may be in error 20 percent, as suggested by Mr. Siebert, if the proper constants are not made use of, as suggested by him. The constants depends upon the frequency and magnitude of pulsations in the steam line. An entirely different constant is used for constant flow from that which is used for intermittent flow.

By referring to Fig. 29, the volume of the receiver space

between the disc and the engine cylinders will be found to be sufficiently great to effectually reduce the magnitude of the pulsations.

In this case the proper constant has been used, depending upon the conditions existing for the work being done. As the conditions mentioned by Mr. Siebert are very extreme, they represent the maximum possible error in case totally improper constants are used. If the disc is installed with a reasonable degree of care and study as to its location, the constant is determinably well within practicable limits.

MR. A. STUCKI*: Mr. Kennedy spoke of one case where a horizontal engine was counterbalanced 100 percent. In such a case it is, of course, quite natural that no vibration in a horizontal direction exists, and he has proven it in a very practical way by supporting the engine temporarily on rollers. I would like to ask what the result in this particular case was in a vertical direction, and whether the vertical blows were not annoying. I have understood that the best results in overcoming the shocks are by counterbalancing part of the reciprocating parts. What is the common practice in horizontal engines? On locomotives we counterbalance, as a rule, one-third of the reciprocating parts.

MR. JULIAN KENNEDY: The result was, of course, that the entire vibration was up and down, but it was on good strong columns. They would take any vibration up and down, but a very little vibration horizontally shakes the whole thing. It is so in most conditions in mill engines that sit on piles. They will stand an enormous amount of up and down lack of balance without affecting anything, but unbalance them horizontally, and you know how it was in New Castle in the Crawford Hotel, when the blooming mill was running, you could see the dishes dance.

I might also add that Prof. Trinks spoke about the short bearings. Those bearings ought to have been made a little shorter than they were, 20 in. instead of 30 in., but it was thought that some people might think that very extreme, and it is very desirable for a manufacturer to have what his patrons

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want and we stretched the idea just a little on them. We believe that engine would be better with bearings 26 in. long than with 30 in. The paper speaks of large bearings well lubricated. The bearings are only half as large as the ones originally proposed.

MR. W. C. CORYELL*: I have not time in which to prepare a discussion but I would like to submit a few notes later on bearing upon the method of plotting foot pounds of work and upon the method of taking care of the fractional stroke at the end of the reversing. I noticed in the address it was assumed that the reversal occurred at quarter stroke. There is a very easy way of taking care of the exact percentage of stroke. It will not make any difference in the total result but it will make a little difference in the shape of the curve and possibly in the amount of work in the individual passes. It also might help to find out any difficulties there might be in the individual passes. Then I might say a little in regard to the hyperbolic formula. I thoroughly believe at the present time that is a good basis, and lastly, I may say something in regard to condensation.

THE AUTHOR: As to plotting quarter strokes I would say that the reason we decided to stop at quarter strokes was because the divisions on our cross section paper were such that it kept the points on the lines of the paper, and if odd percentages were used the points located off the lines of the paper and everything beyond that plotted off the lines. If the paper were ruled as the curve was plotted it would be possible to plot it in any percent. We decided that ¼ stroke was close enough.

MR. W. C. CORYELL: The way we take care of that is that each pass is complete within itself. It starts with the condition of the engine at rest and goes to the condition of being at rest again. Then each pass may be plotted as a simple curve, leaving a slight gap between the individual passes. But it is too technical to describe off hand how it is taken care of.

MR. L. IVERSEN†: Prof. Trinks spoke of "British Conservatism" of the master mechanics of this country and stated

*Engineer, Youngstown, Ohio.

†Chief Engineer, Mesta Machine Company, Pittsburgh.

that Mr. Kennedy had been instrumental in overcoming some of it. I wish to add a few interesting facts to his statement. In making proposals for engines of this type, we often start out with journals larger in diameter and of considerably greater length than we consider correct. In trying to make the sale, our engineer is told that one competitor has bid on, say, 3 inch larger bearings and another one on 4 inch larger bearings and that consequently their engines are more liberally proportioned. No attention is paid to the question whether these larger sizes are required or not. In order to not look stingy or cheap and in order to make the sale, we have, in the past, been compelled to come up to the other men's sizes, because we found that reasoning at such time does very little good. Knowing this sad, but true condition we turn in proposals which we know are out of proportion.

Just as soon as engineers will quit tabulating pin and journal sizes and judging an engine by these sizes regardless of actual requirements, the more thoughtful among the engine builders will redesign their engines and will introduce better proportions.

Engineers should be thankful to Mr. Kennedy for taking up the bearing question in this case and for sanctioning sizes which fit the requirements.

The Author: We believe that the question of bearing design is probably largely responsible for the small amount of power consumed in friction. This feature, coupled with machined pinions and proper mill couplings, doubtless produces these results.

We quite agree with Mr. Iversen that the engineering profession should feel grateful to Mr. Kennedy for the important step which he has taken in proving that an engine for this class of work can be built with bearing so designed as to greatly reduce the amount of power which had formerly been wasted in overcoming friction, and at the same time obtain sufficient strength.

The writer quite agrees with the several members who have proposed the adoption of a standard method of recording results of blooming mill tests. It would certainly be a great

aid to this end if this matter could be taken up by a suitable committee which could standardize the testing of all rolling mill engines.

We sincerely trust that there may be published the results of other tests of blooming mills with which the results of this test may be compared. The value of this work depends upon the amount of information which is made available by numerous published tests.

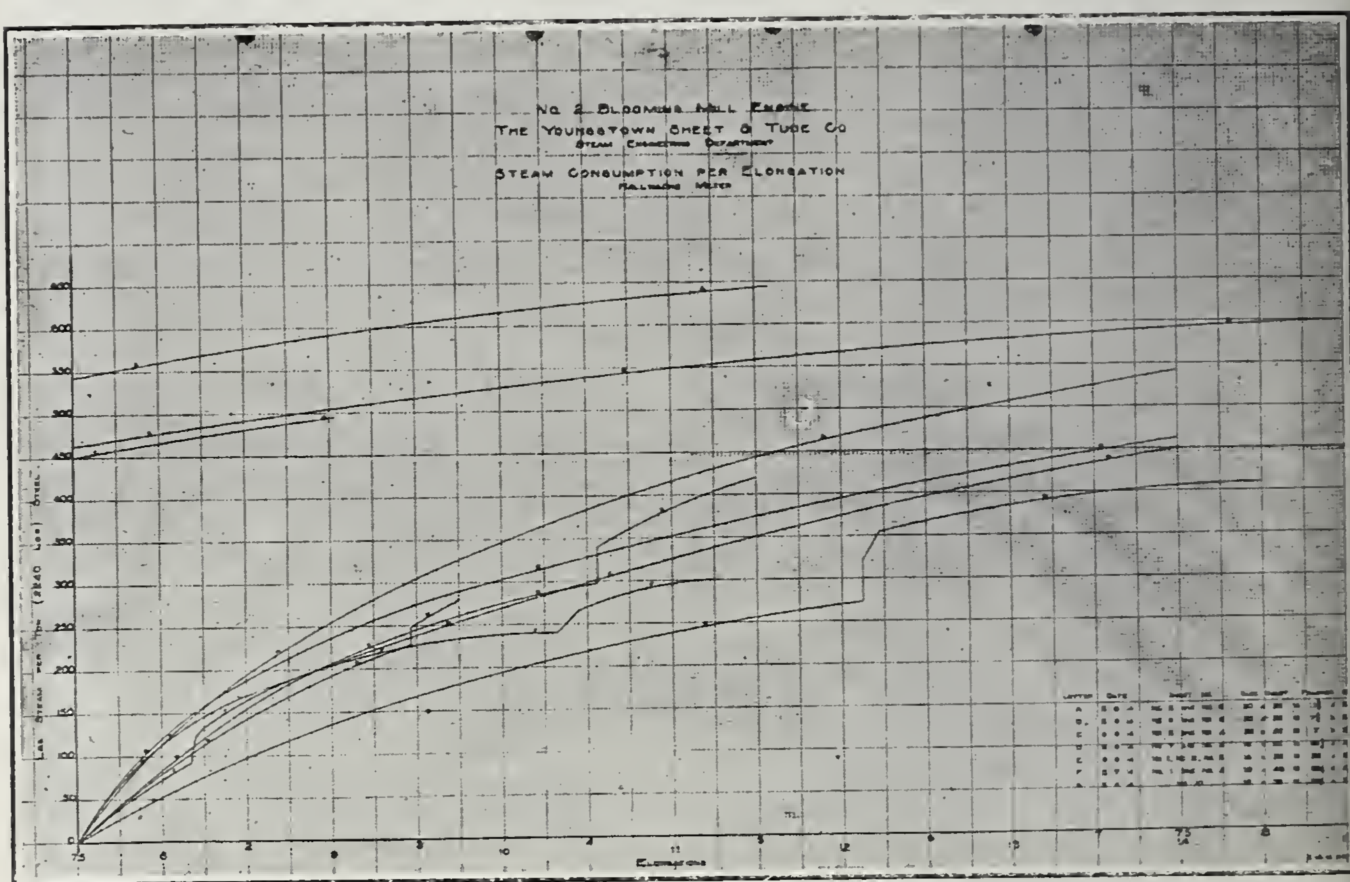

Fig. 30. Steam Consumption per Unit of Elongation for various sizes of ingots.

The real measure of the operation of the mill described in this test is in the total steam used and tonnage rolled in regular operation. Figure 30 exhibits a steam consumption per long ton of metal rolled for various sizes. The maximum tonnage rolled on this mill in 24 hours was 2441 tons On this run, 761 ingots were rolled, having an average weight of 3.2 tons. The best steam consumption per ton of steel rolled for 24 hours is 381 lb. per ton. During one month this mill has used 473 lb. of steam per ton of steel rolled. These values represent readings taken from integrating steam meter and show the efficiency of the mill under normal operating conditions for various lengths of time.

CORRESPONDENCE

MR. J. A. KNESCHE:* In reading over this very excellent paper the question has occurred to me why the "spread" of the steel is figured, since the height of the steel is known from the roll-gauge (which was calibrated when the test was over) and furthermore since a suitable method seems to have been in use during the tests for determining the length of the steel. The computed "spread," while, of course, a matter of much interest, appears to be superfluous in this case. It seems to me that since the area of the steel after each pass is of so much importance, the determination of the average width in each pass would be more accurate if the weight and length of the steel and the height in the pass were used in determining the width. This would eliminate the perhaps somewhat uncertain computation of the "spread."

The steam consumption of this engine certainly seems most remarkable, especially when it is remembered that under light loads the engine is partially controlled by throttling the steam. I agree with the author of the paper that this exceedingly economical steam consumption is brought about by the one-lever control. It is not stated when the engine was built, but I presume it is practically new and in an ideal state as regards repair. Judging from the size of the cylinders and the given weights of the ingots rolled, the engine is very liberally proportioned for the work it has to do. As a consequence its average operating revolutions and piston speeds are probably relatively low. I believe the author speaks of the large percentage of power required for acceleration and retardation. Would not this percentage be considerably reduced if the engine were given more work to do? In other words. if the engine drove a heavier mill, which, judging from its size, it should be abundantly able to do. The question of repair and up-keep and the consequent loss of tonnage are big features in all rolling mills and the endeavor of all engineers is constantly in the direction of avoiding

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the latter. If lightening any of the moving parts were to bring about a reduced steam consumption, the value of this reduced steam consumption would probably be small when compared with the value of the time and tonnage lost during possibly more frequent repairs. The up-keep and the loss of time from breakdown in blooming mill reversing engines under high speeds are usually abnormally large. In one blooming mill reversing engine of which I know, the piston speed is sometimes between 1200 and 1300 ft. per min. and breakdowns frequently occur.

In computing the steam from the indicator cards, Mr. Nibecker states that at first an allowance of 30 percent was made to cover the condensation and leakage losses. In Vol. 36, No. 20 of *Power* tables and formulae are given for the computation of the approximate steam consumption. The formulae employ empirical constants, while the several tables for the different types of engines show the steam accounted for by the indicator cards with different cut-offs and with various pressures. These same tables and formulae are also given in the metric system in the Engineers' handbook *Huette* (German).

The point which I am trying to make is this; since the steam consumption, computed by the method given in the volume of *Power* referred to above, agrees in the main with the results of tests made by noted experimenters and engineers (for the types of engines in question) and further, since there can be no dispute about the theoretical dry steam, as shown by the indicator cards, it would seem to follow that the condensation losses as obtained by the method set forth in *Power* must be reasonably correct.

Further, Mr. Nibecker's condensation losses (the 30 percent) seem to be in accord with what Dr. Thurston says on this subject. On p. 501, Part 1, in his *"A Manual of the Steam Engine,"* he states that through painstaking experiments on a simple 18 x 42 Corliss engine he found the following:

Cut-off 58.9%; cylinder condensation 22.73% of total steam furnished to engine.

Cut-off 44.3%; cylinder condensation 27.08% of total steam furnished to engine.

Cut-off 33.0%; cylinder condensation 33.87% of total steam furnished to engine.

Cut-off 13.1%; cylinder condensation 50.07% of total steam furnished to engine.

For description of these tests see the work referred to.

In a foot note on p. 596 of the same work by Dr. Thurston, reference is made to the Augsburg triple expansion engine test by Prof. Schroeter where the total cylinder condensation seems to have ranged from 16 to 20 percent.

In view of the preceding facts and without referring, for the present, to Mr. Nibecker's figures, it would seem that the cylinder condensation of the Youngstown engine in question should range itself somewhere between the tests of Dr. Thurston and Prof. Schroeter. Furthermore, nothing seems to have been said of the quality of steam used by the engine in question. It is well known and is also stated in *Huette* and on p. 706 in the volume of *Power* referred to above, that with a cut-off of from 40 to 25 percent in the high pressure cylinder and a superheat of from 175 to 250 deg. Fahr., the cylinder condensation may be prevented entirely.

The paper further states that the computed average value of the steam consumed per i. h. p. hour is about 21 lb. This is a very small figure when the very fluctuating demand for power and the very irregular speed of an engine of this type are considered.

In this connection, I think it would be interesting to know what proportion the *actual average* load on the engine bears to the full load during the rolling of the ingot in question. I think it would be proper to consider the full load that load at which the most economical steam consumption is obtained and from the size of the engine given, it would appear this most economical load would be reached when the engine is developing say about 6000 i. h. p. at an approximate speed of from 60 to 65 r. p. m. If we know what horsepower the engine developed when the average value of the steam consumed was about 21 lb. per i. h. p., as stated in Mr. Nibecker's paper, we could make interesting comparisons between the given values for the steam consumption and the general form of steam consumption curves, as given in the work of Dr. Thurston on p. 835.

Mr. Nibecker also found an average steam consumption of 18 lb. per i. h. p. hour as obtained with the Hallwachs steam meter. This approaches very closely the ordinary compound condensing Corliss engine steam consumption at a 100 percent load operating continuously. The above steam meter figure is presumably for dry steam also; if for instance the steam had been superheated (having a quality of say 110) the steam consumption expressed in dry steam would really become 19.8 lb. per i. h. p. hour.

It happens to be a part of my duties to see that several steam meters record the flow of steam correctly and I know from experience that they will not do so under all conditions. If we had a sketch with dimensions showing the location of the throttling disk of the Hallwachs steam meter in the steam line, the location of the engine, etc., we would be able to say with more certainty to what extent the indications of the steam meter could be relied upon as being strictly accurate. I suppose, owing to the large amount of steam used, it was not possible to calibrate the steam meter in place under working conditions.

In Germany in 1909, two types of steam meters were tested, one a Bayer and the other a Gehre meter, the latter belonging to the velocity type meter, to which type the Hallwachs meter also belongs. These tests are described in detail in the *Zeitschrift Des Vereins Deutscher Ingenieure p.p.* 257 to 259, Feb. 1910 and are also quoted at considerable length in the *Engineering Magazine* for January 1913. Two boilers were set aside for these tests, the feed water being carefully measured and all thermometers calibrated. Facilities existed for reading the water glass to within 0.039 in. and some of the tests lasted for nine hours. The entire series were divided into three groups. For the sake of brevity the figures following refer only to the velocity type meter.

In one group of tests the steam was permitted to escape in a steady stream into the atmosphere and the errors in the different runs ranged from —2.1 percent to +1.2 percent. In another group of tests the steam was taken by a compound engine developing about 300 h. p. at 76 r. p. m. with a cut-off in the high pressure cylinder of approximately 40 percent. It

was found that in the runs for this group of tests the errors were from 0 to 5 percent. In still another group of tests the steam was permitted to escape under violent fluctuations into the atmosphere. These fluctuations were obtained by placing a specially constructed valve, in a manner similar to an ordinary two-way cock, in the steam line. The revolving part of the cock, fitted with a stem and pulley, was driven at speeds ranging from 40.5 to 157 r. p. m. the steam meters being about 65 ft. away from this device causing the fluctuations. The errors in this group of tests ranged from + 15.0 to + 25.0 percent. In view of the above tests it seems to me that there may be a possibility that Mr. Nibecker's steam meter readings can not be accepted as final at the present time, unless special precautions were taken at the time of the test to make the steam meter readings accurate.

My own opinion is that the steam consumption as given is too low for the type of engine and for the conditions under which it must necessarily operate. In a letter which I sent to the Secretary of the Society to be read at the time Mr. Nibecker's paper was presented, I stated among other things that I agreed with the author that—"this exceedingly economical steam consumption is brought about by the one-lever-control." This statement was intended to convey my opinion that the one-lever-control (in connection, of course, with other steam economy producing factors) would give the lowest steam consumption. At this writing, I have nothing at my disposal from which I could determine the average load on the engine during the entire rolling cycle of the ingot on which the test was made, but it would, perhaps, not be over 3000 h. p. and probably not that much. If my estimate of 6000 h. p., as given before for the full load of the engine, is approximately correct, then 27 lbs. of steam per i. h. p. hour on a 50 percent load would still be exceedingly economical for this type of engine if we care to accept as a guide, curves No. 5 and No. 6 on p. 835 of the work by Dr. Thurston to which I have previously referred in this discussion. The average steam consumption for five ingots which Puppe found in his blooming mill engine tests on a 43¼ and 61 by 51 twin tandem condensing reversing engine seems to have been

33.8 lb. per i. h. p. hour, while his computed steam consumption was about 6.65 percent less than the above amount. This engine was practically new at the time he made his tests.

An extensive test of the kind presented to the Society in Mr. Nibecker's paper is always made with considerable difficulty in the mill where the operating personnel is usually jealously watching the loss of every second of time and where those in charge of the operating end of the mill, either through ignorance, indifference or for other reasons, may fail to be in full sympathy with the work. Under such difficulties, which are perhaps always present to a certain extent in every mill, the planning of a test of this kind, the training of the observers and the painstaking care required for working up the mass of data, all reflect great credit on those responsible for the test. For all of these reasons, I desire to congratulate Mr. Nibecker on his excellent paper, of which type many more should be presented to this Society.

THE AUTHOR: In regard to the remarks of Mr. Knesche concerning the calculation of the spreads, we would say that as it was desired in this test to obtain data representing the average operation of the mill, it was impossible to make accurate measurements of the length of the bloom after each pass. The lengths were estimated by two observers sighting from each end of the bloom to a scale placed on the mill guides. In nearly every case the bloom length was estimated while in motion and the results could only be used as a rough check on the length as calculated from the thickness and spread determined by the data taken during the pass.

Figure 29 shows the piping as connected to the engine. As the volume between the steam meter disc and the cylinder is approximately 8½ times the volume of one high pressure cylinder, the fluctuations in the flow should not be sufficient to effect the accuracy of the steam meter.

MR. W. C. CORYELL: It is intended in this discussion to show:

First: The leading paper is correct with regard to the work required to roll steel;

Engineer, Youngstown, Ohio.

Second: That the cut pinions and spindles used in this mill save 18 percent of the power; and

Third: That the steam consumption as shown by the indicator card is 575 pounds per gross ton of steel rolled.

On the 29th of last November, The Youngstown Sheet and Tube Company gave me the privilege of taking part in the tests which they were making on their large blooming mill engine. They also gave me a set of the cards, five of which were of the open diagram type, three of the closed diagram type, all being in perfect condition. The following data are derived from this set of cards.

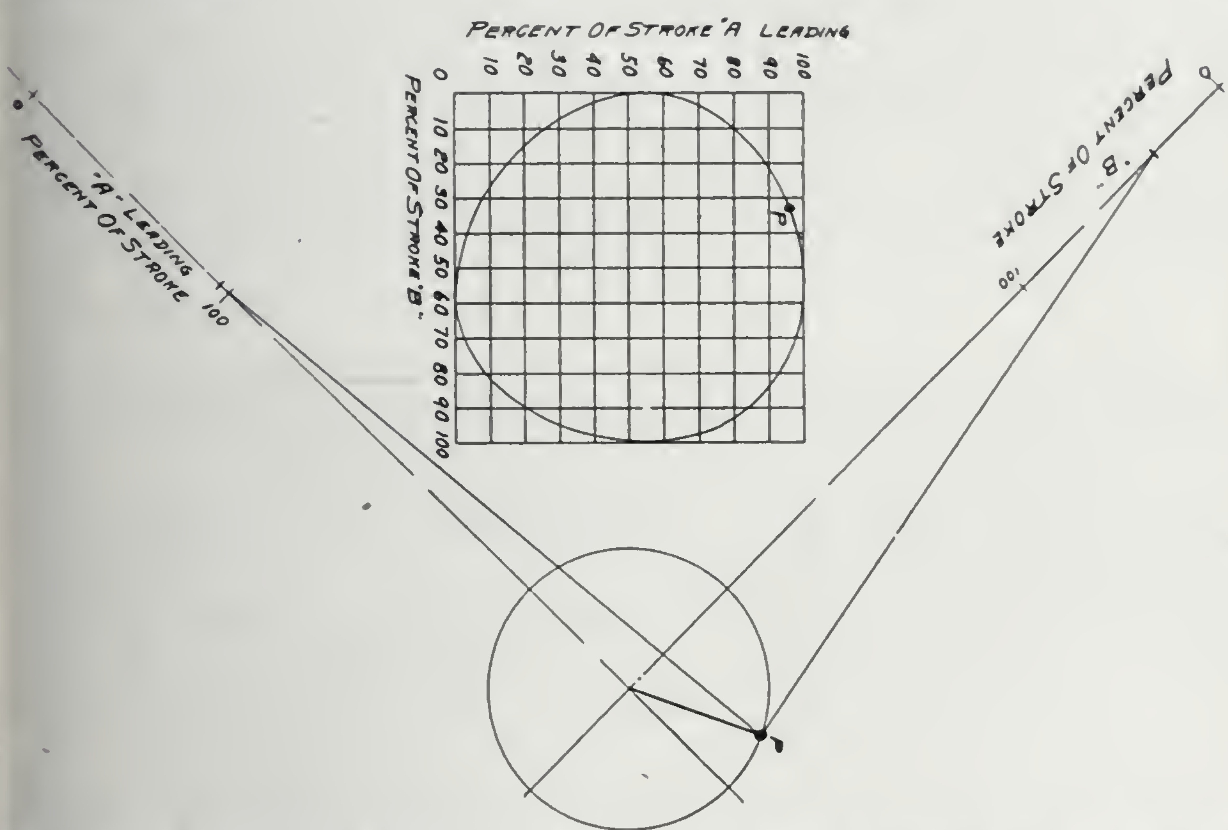


Fig. 31. Relative Positions of Pistons with Cranks at 90 degrees.

In working up and plotting the M. E. P. curve each pass is treated separately. This permits adhering to the exact fraction of the stroke which is made at the reversal. This fractional stroke is important for the reason that a high steam pressure exists, due to plugging, in four of the eight cylinders at the instant of reversal. Also, when the passes are plotted separately, the sheets can be more readily filed or bound into books.

Then, in plotting, it was found to be best to use the rectangular method. It must not be forgotten that we are dealing with artificial units (M. E. P.'s) and not with real pressures. Due to the fractional strokes at reversals the horizontal spacings

on the curves are not uniform, hence a small error in the form of a triangle occurs when the point to point method is used.

In working up closed diagrams, it is sometimes difficult to determine the point of reversal on all the cards, especially when it is not a plugging card. Figure 31 shows a curve from which the piston position can be determined if one of the other piston positions is known.

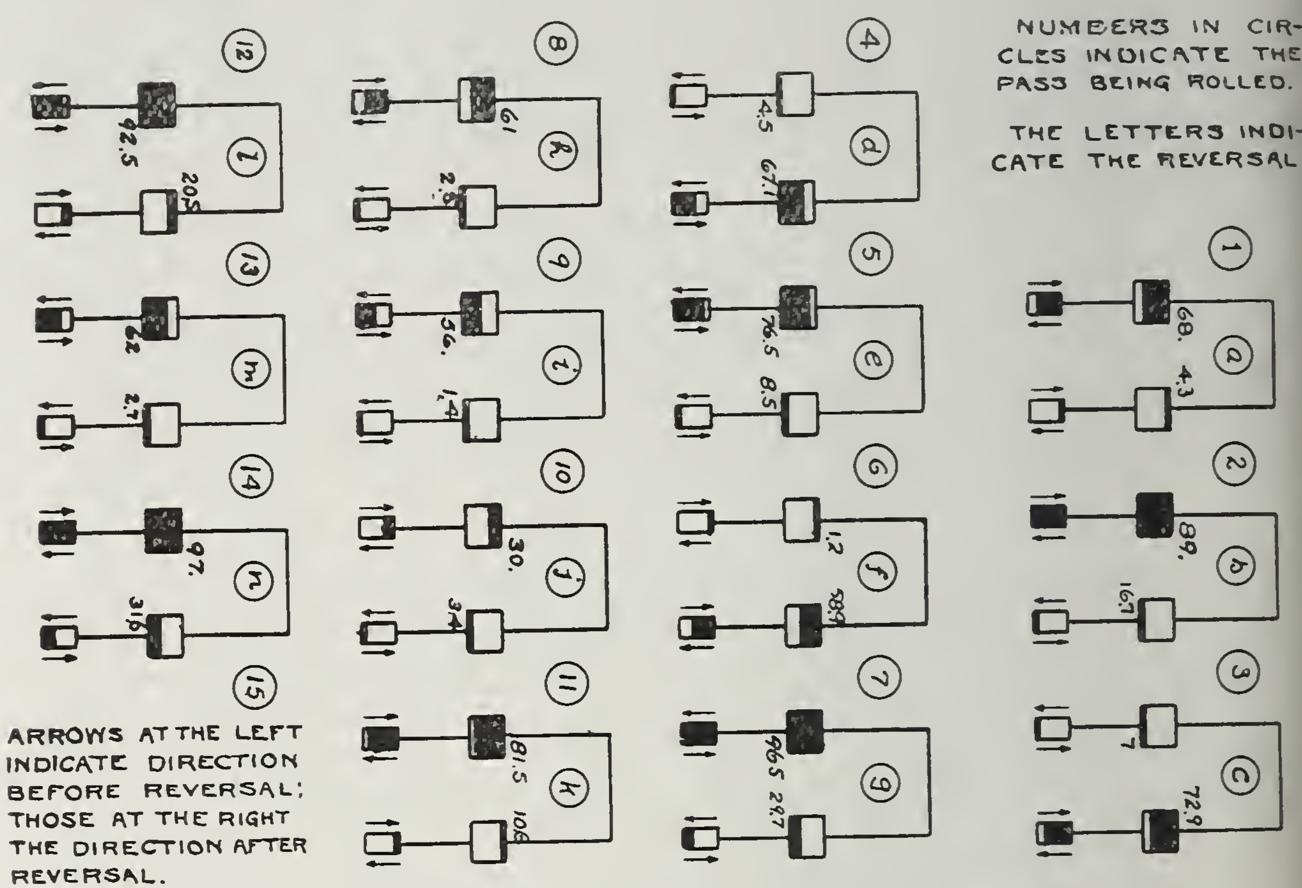


Fig. 32. Position of Pistons at Time of Reversals.

It should be observed that the reversal points are nearly always so located that the pistons of one side or the other nearly complete full stroke. If enough inertia exists to carry the crank pin past dead center, then the re-expansion of the compressed steam in two of the cylinders drives the engine ahead, until the other side of the engine approaches its dead center. That this tendency exists can easily be seen by the diagrams in Fig. 32.

No serious delays or difficulties occurred in rolling this ingot, so the data derived from the one set of cards may be considered a reasonable average. The M. E. P. curve is shown in Figs. 33 to 46. To show how well the engine is balanced the M. E. P. for the left side is shown in a light full line, that of the right in a light dotted line and the total in a heavy full line.

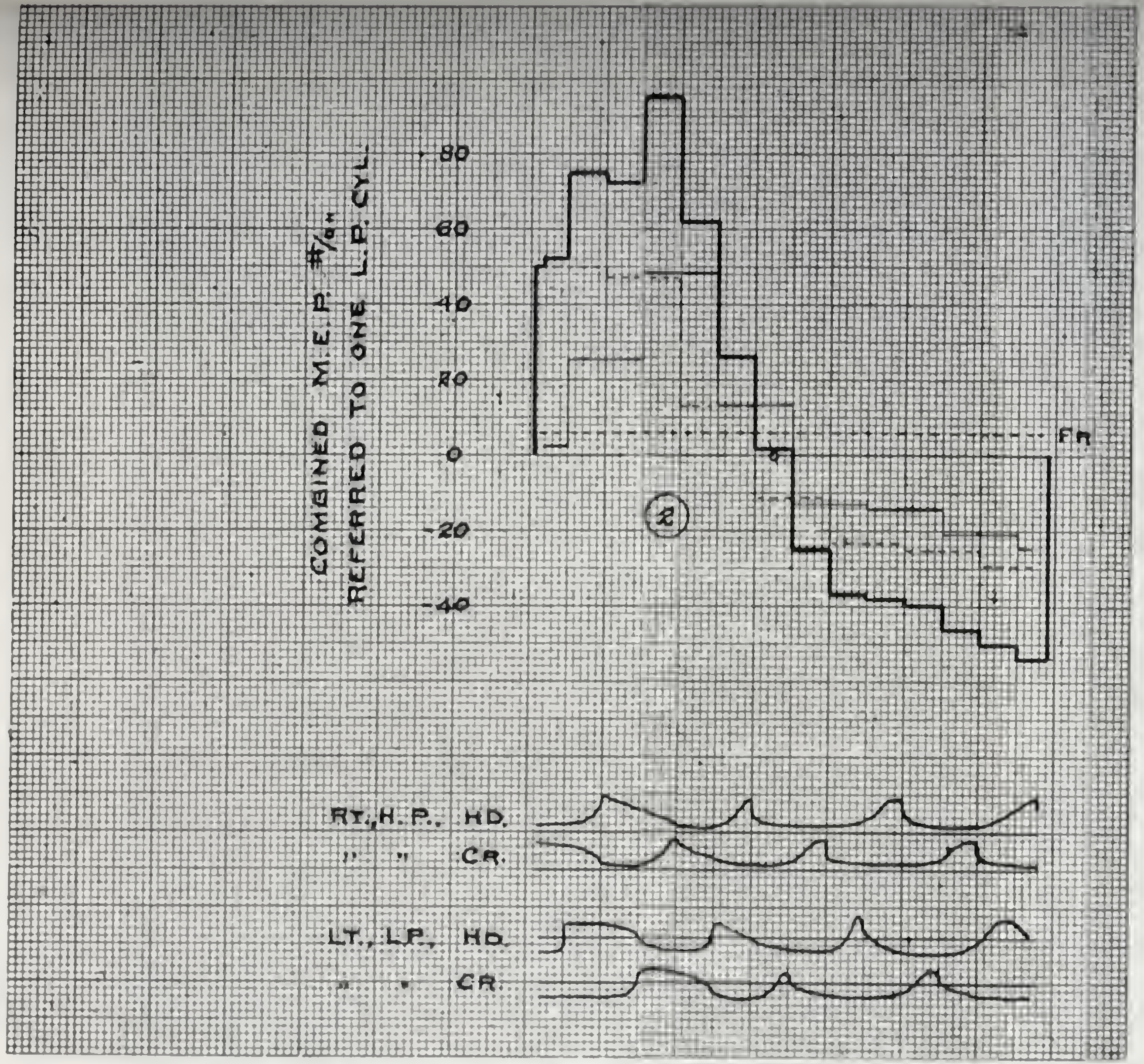


Fig. 34. M. E. P. Curve, Pass No. 2.

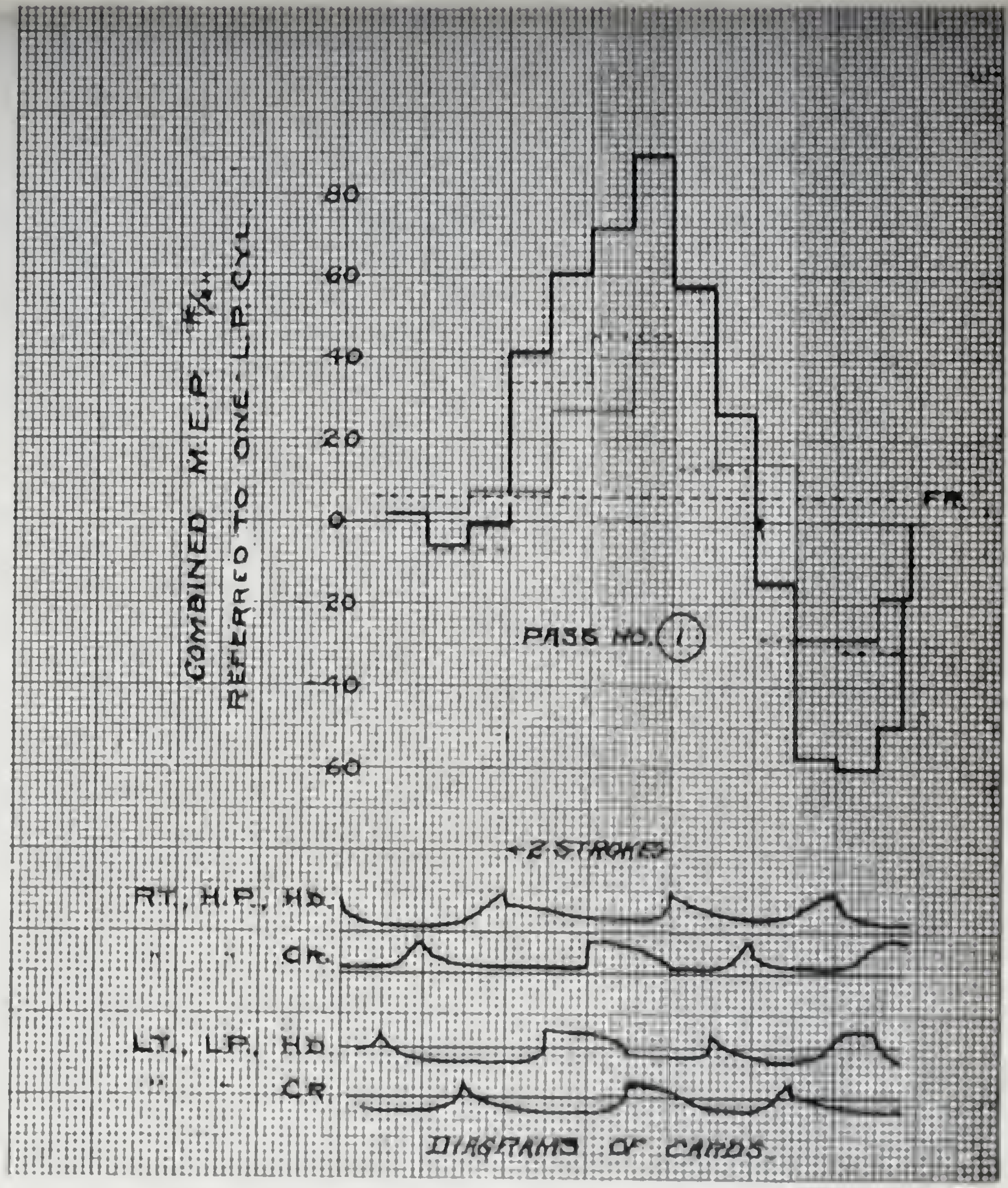
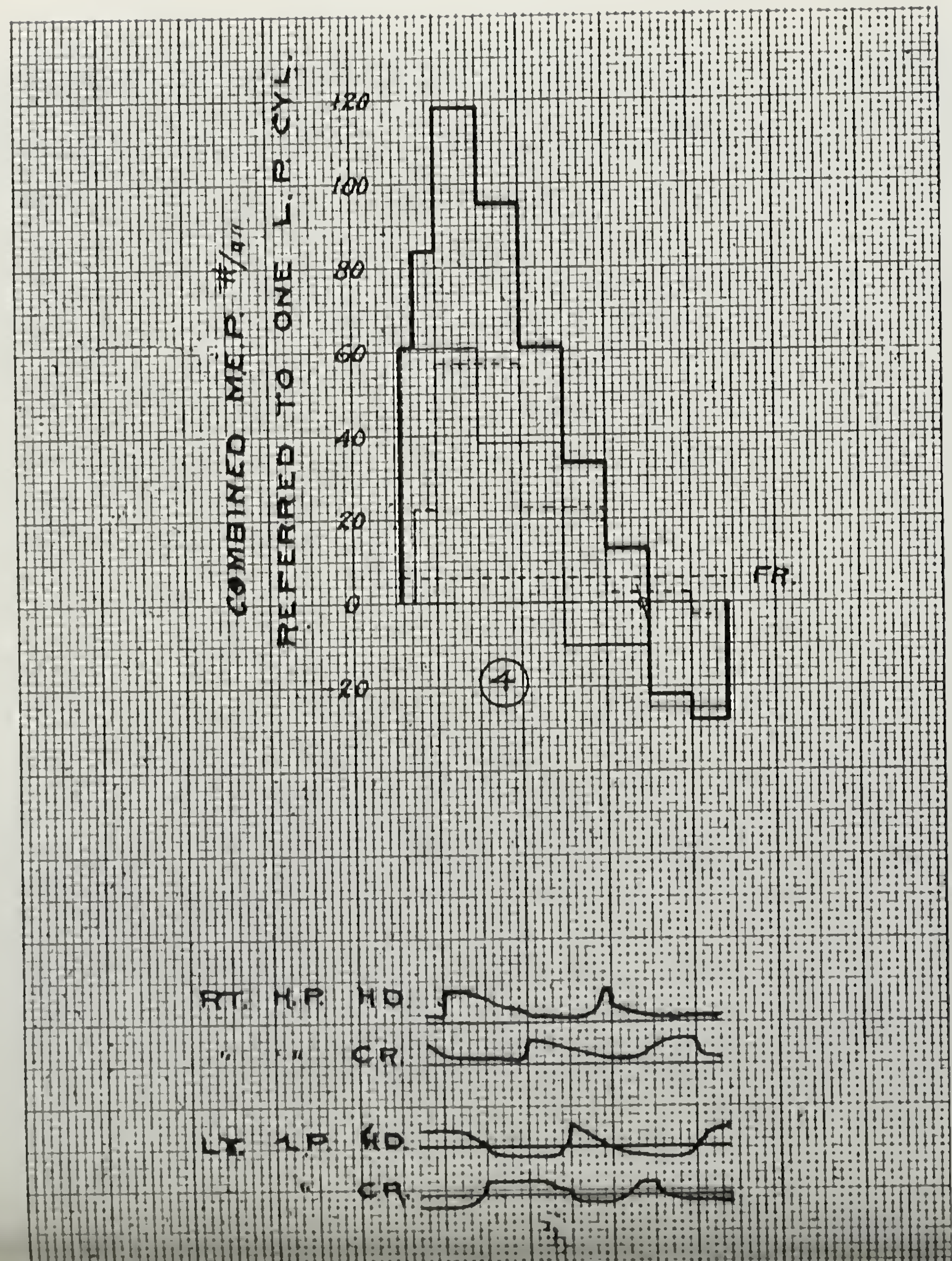
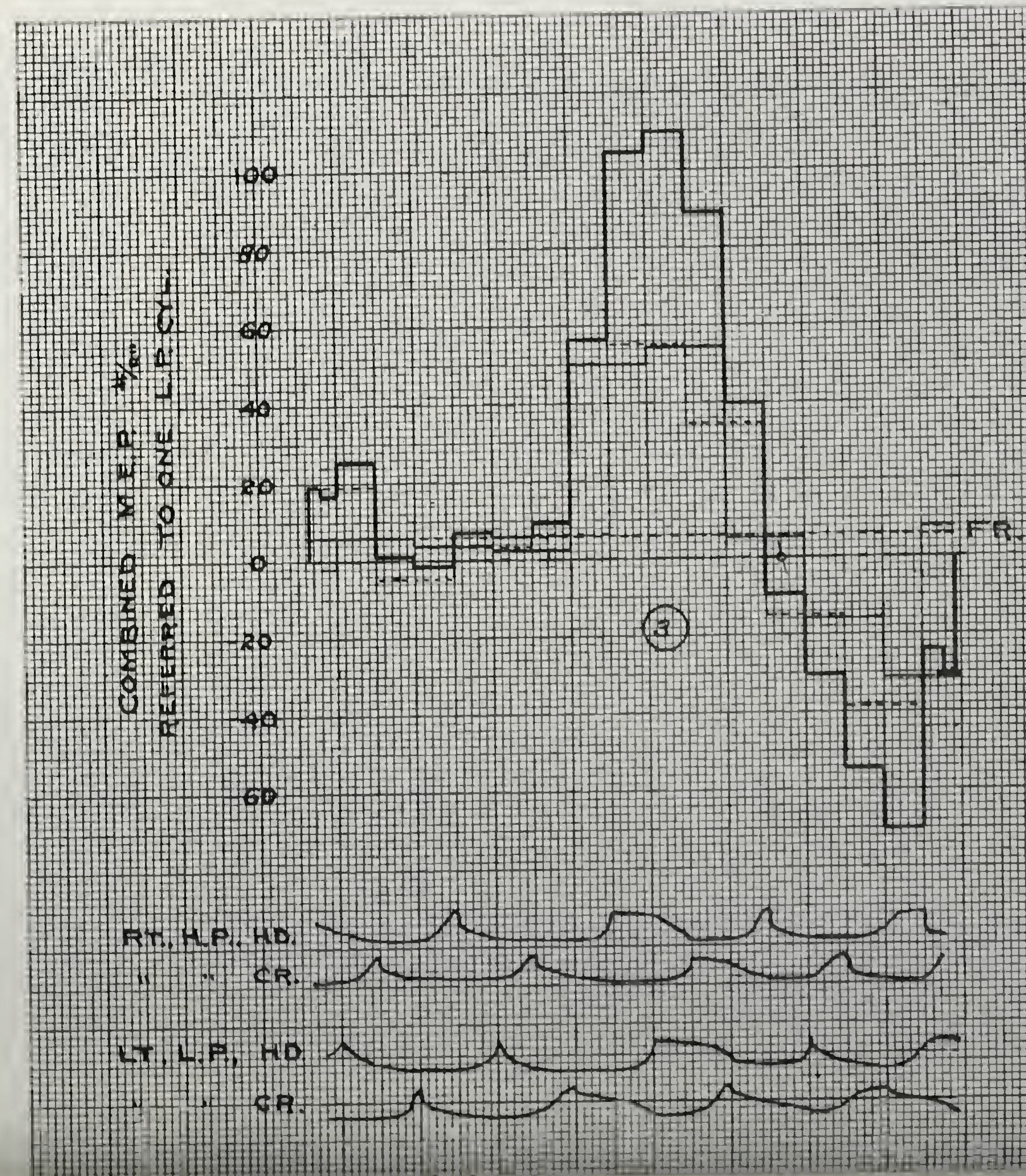


Fig. 33. M. E. P. Curve, Pass No. 1.



COMBINED M.E.P. #/□"
REFERRED TO ONE L.P. CYL.
120
100
80
60
40
20
0
20
FR.
4
RT. H.P. HD.
" " CR.
LT. L.P. HD.
" CR.



COMBINED M.E.P. #/□"
REFERRED TO ONE L.P. CYL.
100
80
60
40
20
0
20
40
60
FR.
3
RT. H.P. HD.
" " CR.
LT. L.P. HD.
" " CR.

During the test magnetically operated pencils were mounted upon the indicators for the purpose of recording the reversals, the position of the links, the throttle and the entering and leaving of the piece. But the records are not always consistent with the M. E. P. curve and since none of these events are essential to a report on work or steam consumption they are omitted.

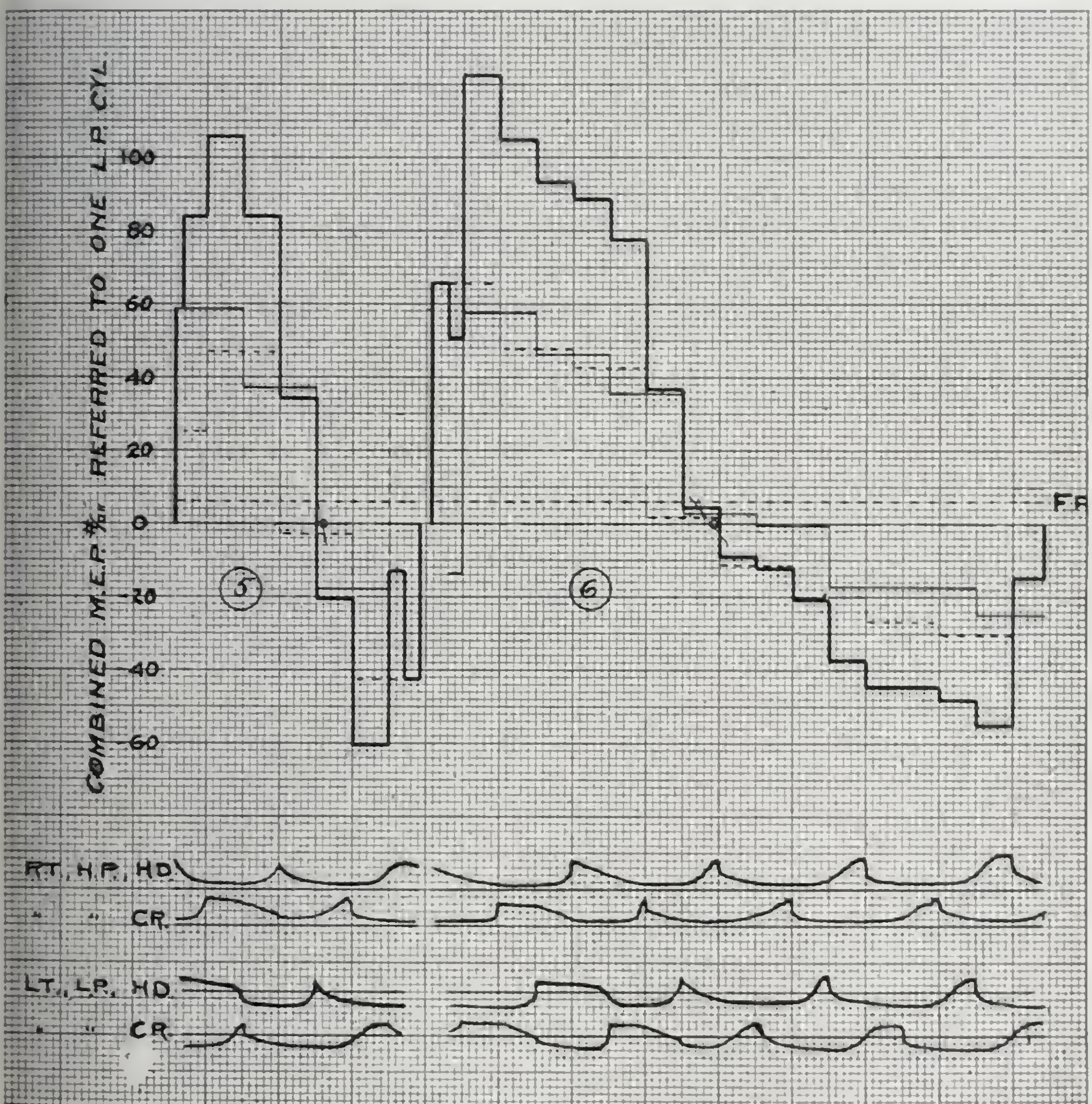


Fig. 37. M. E. P. Curve, Passes No. 5 and 6.

Friction M. E. P. is assumed to be constant. The increase in friction during the rolling of the piece is ordinarily figured as a part of rolling. The work as calculated from the M. E. P. curve is shown in Table 11. The column for total positive work includes:

Table No. 11. Distribution of Work as shown by M. E. P. Curve.

Pass No.	Total Positive Work Ft. Lbs.	Total Negative Work Ft. Lbs.	Rolling & Friction Work Ft. Lbs.	Friction Work Ft. Lbs.	Net Rolling Work Ft. Lbs.
1	3,680,000	1,824,500	1,855,500	640,000	1,215,500
2	4,109,900	3,000,000	1,109,900	892,000	217,900
Edge 3	4,330,000	2,092,900	2,237,100	640,000	1,597,100
4	4,160,000	483,600	3,676,400	510,000	3,166,400
5	3,160,000	1,131,000	2,029,000	437,000	1,592,000
6	6,300,000	3,092,000	3,208,200	1,100,000	2,108,200
Edge 7	7,230,000	2,322,300	4,907,700	807,000	4,100,700
8	7,800,000	3,447,300	4,352,700	1,000,000	3,352,700
Edge 9	9,630,000	2,780,100	6,849,900	1,040,000	5,809,900
10	7,400,000	1,330,400	6,069,600	780,000	5,289,600
Edge 11	10,070,000	2,803,900	7,266,100	1,035,000	6,231,100
12	9,840,000	3,111,500	6,728,500	1,260,000	5,468,500
Edge 13	10,500,000	1,898,400	8,601,400	1,140,000	7,461,400
14	12,530,000	5,472,000	7,058,000	2,035,000	5,023,000
Edge 15	9,670,000	1,796,900	7,873,100	1,892,000	5,981,100
Total	110,409,900	36,586,800	73,823,100	15,208,000	58,615,100

110,409,900 ft. lbs. = 100% = Total Work

- 15,208,000 ft. lbs. = 13.8% Friction
- 36,586,800 ft. lbs. = 33.3% Negative Work
- 58,615,100 ft. lbs. = 52.9% Rolling

(a) The inertia put into the engine and mill.

(b) The work of friction from starting to stopping, and

(c) The work of rolling the piece.

The coefficients for the individual passes are not given, because no precise measurements were taken to determine the exact size and shape of the pass. However, the coefficient for the mill is easily calculated as follows:

Average size of ingot, inches	18.5 × 20.5
Sectional area of ingot, sq. inches (A)	380.0
Length of ingot, feet (L)	4.75
Weight of ingot, gross tons	2.56
Size of finished piece, inches	4.875 × 7.5
Sectional area of finished piece, sq. in. (A)	35.4
Length of finished piece, feet	51.0
Approximate time of rolling, seconds	90.0
Ratio of sectional areas $\frac{\text{(before mill } A)}{\text{(after mill } a)}$	10.75
Hyperbolic logarithm of ($A \div a$)	2.375
Net work to roll ingot, foot pounds	58 615 000
*Coefficient, $C = \dfrac{\textit{Foot pounds}}{A\ L\ hyp.\ log\ \dfrac{A}{a}} =$	13 700

This is a low coefficient and there is an unusual condition which accounts for it. In a large three-high mill, tested by the

*See Proceedings Engs. Soc. West. Pa., 1913, vol. 29, p. 533.

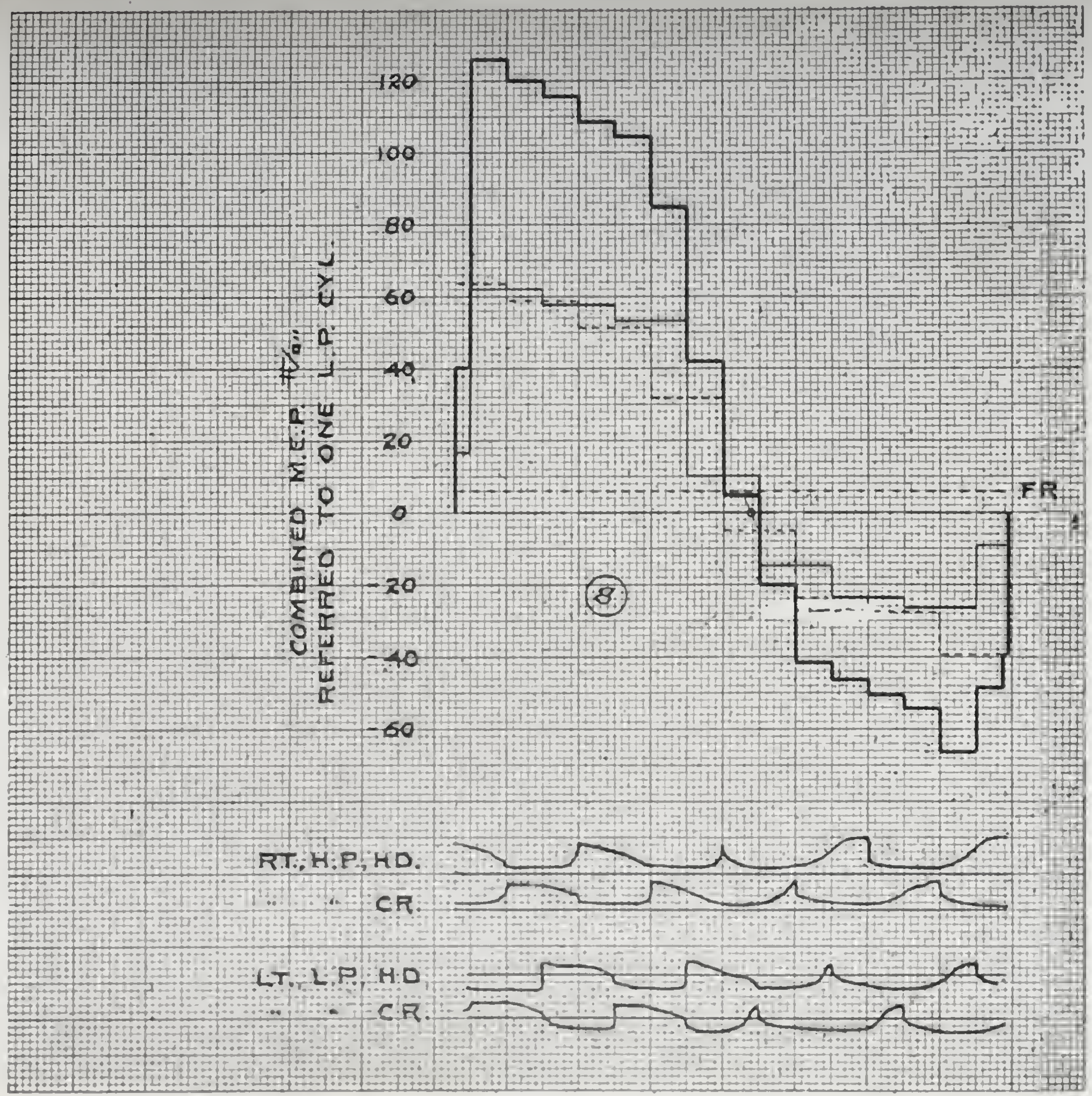


Fig. 39. M. E. P. Curve, Pass No. 8.

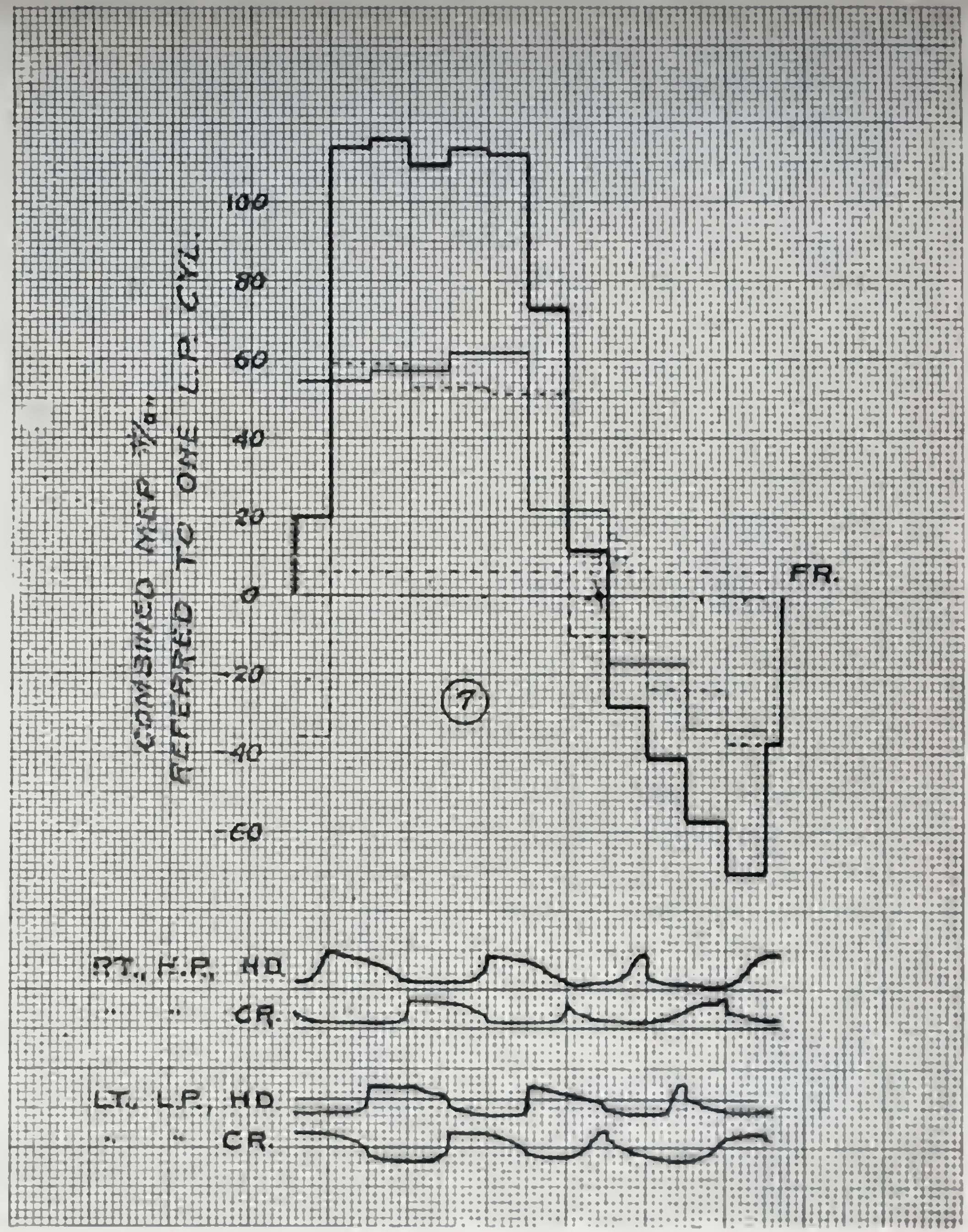


Fig. 38. M. E. P. Curve, Pass No. 7.

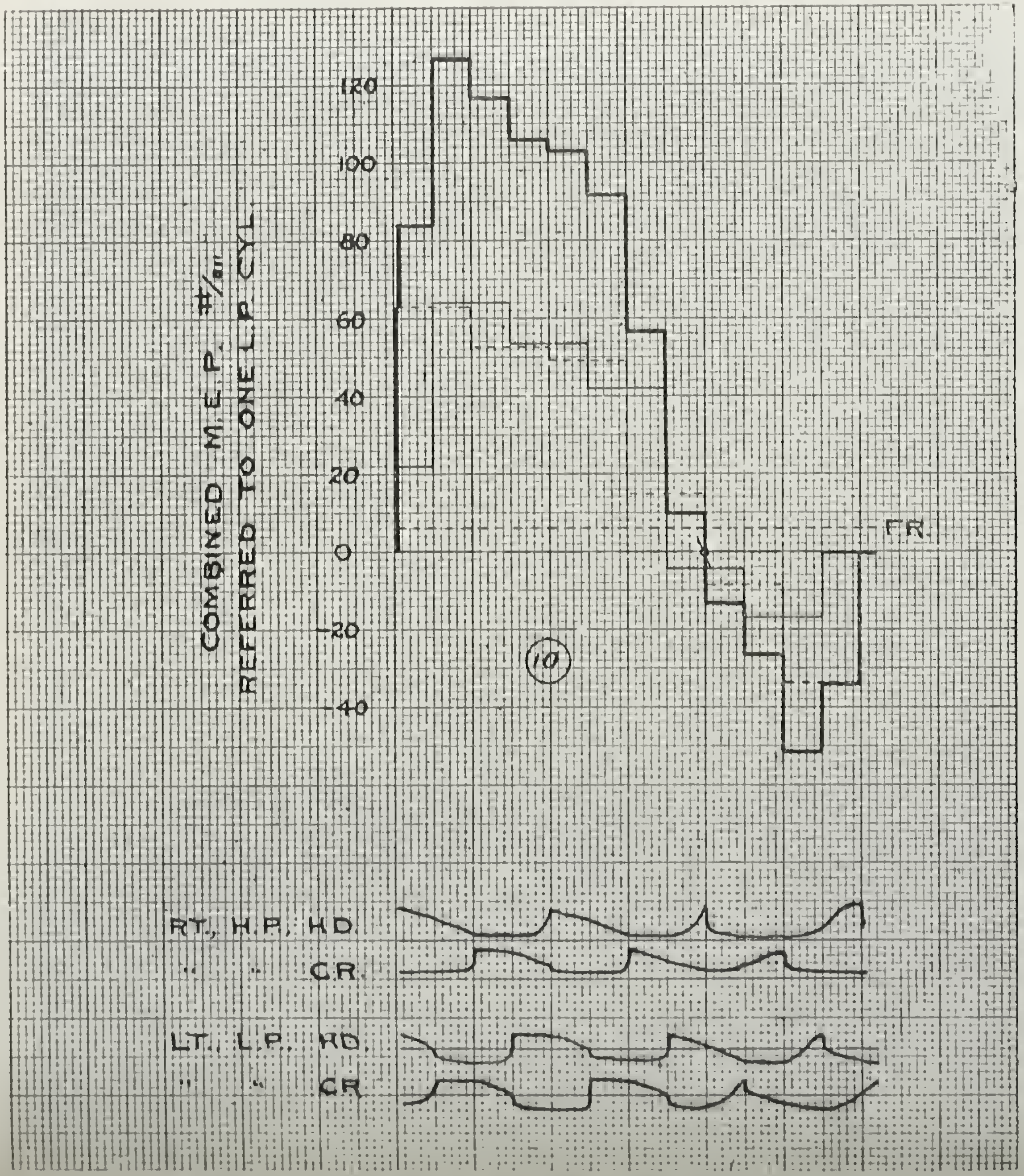


Fig. 41. M. E. P. Curve, Pass No. 10.

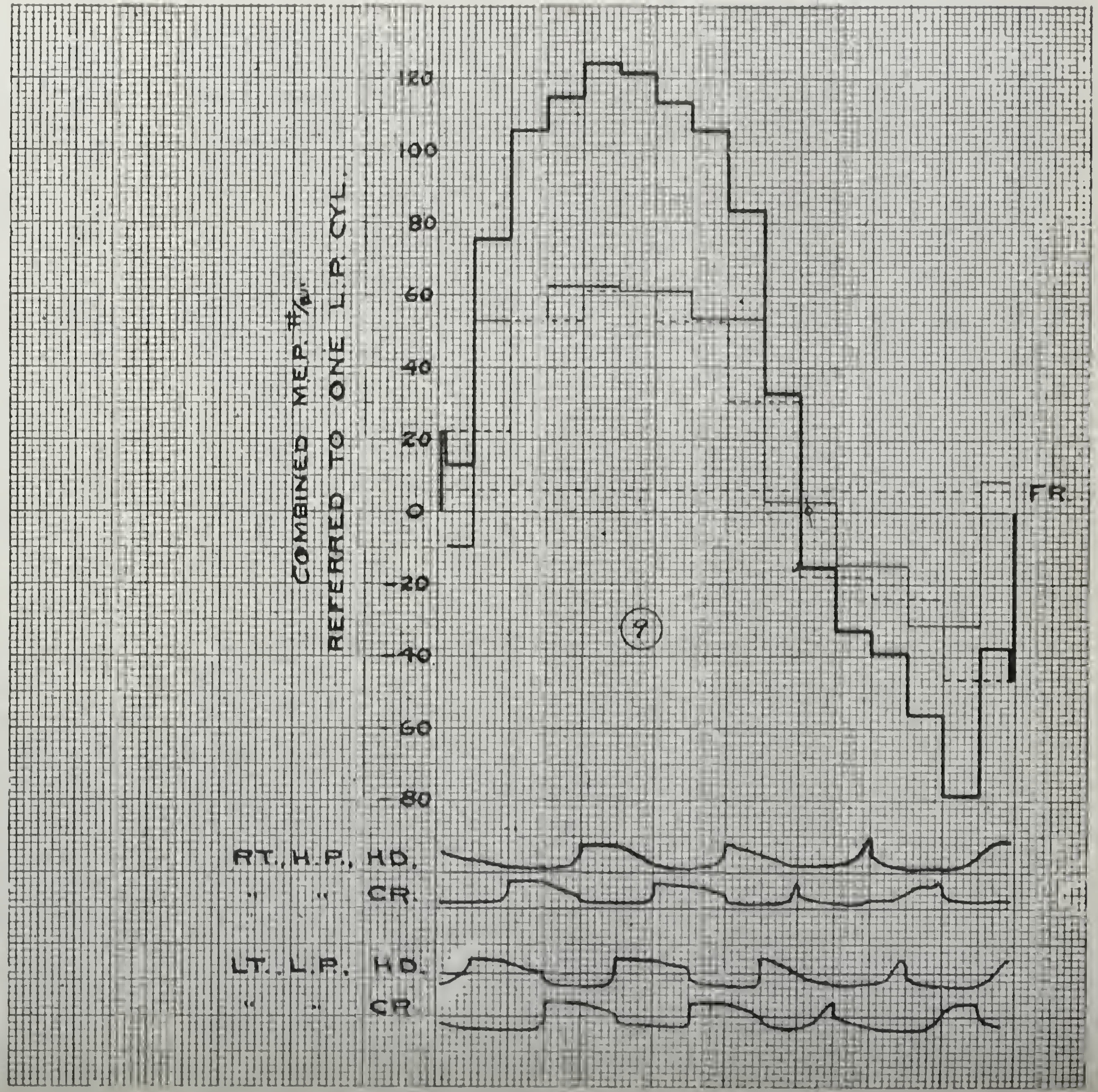


Fig. 40. M. E. P. Curve, Pass No. 9.

writer, a 19 in. by 21 in. ingot of 2.68 gross tons weight was reduced in nine passes to a bloom 7.75 in. by 7.875 in. The time required was about 45 seconds. Now this mill had several advantages; the reduction was less; the rolling was faster; consequently the average temperature was higher; the engine is non-reversing and has Corliss valves instead of piston valves. Its coefficient was 14 200.

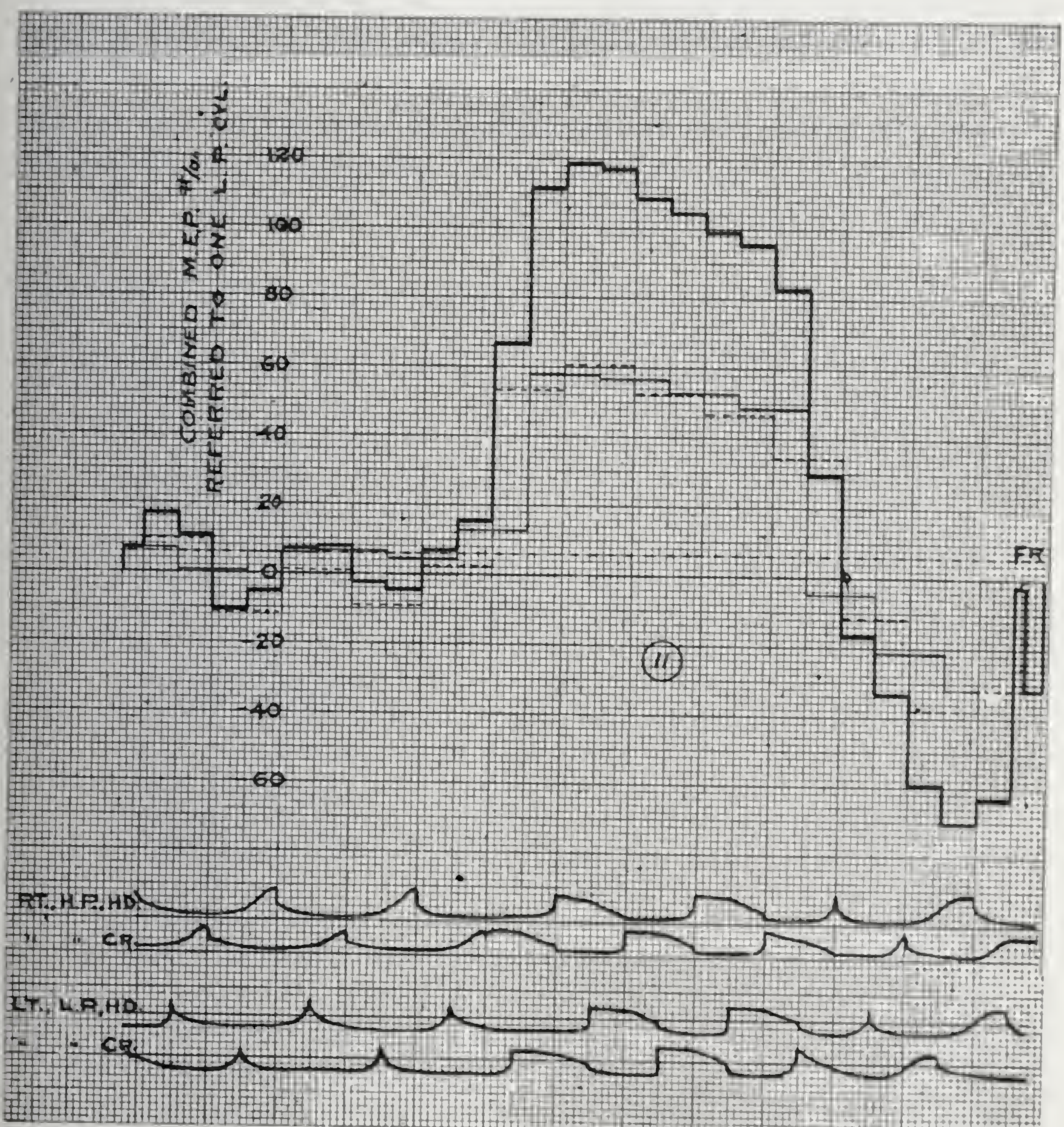


Fig. 42. M. E. P. Curve, Pass No. 11

If we leave off the last three passes in the test of the two-high mill, we have a somewhat comparable condition, except the engine of the three-high mill still has the advantage and, therefore, should be the lower of the two.

Size of 12th pass, inches	7.5×8.125
Sectional area of 12th pass, sq. in. (a)	61.0
Ratio of sectional areas $\dfrac{(\text{before mill } A)}{(\text{after mill } a)}$	6.2
Hyperbolic logarithm ($A \div a$)	1.824
Net work to roll piece, foot pounds	39 950 000
Coefficient, C	12 000

Now in the three-high mill there were rough cast pinions and spindles, and in the two-high there were machined pinions and spindles. No direct tests have been run to show the increased efficiencies due to machining of these parts, but we can approximate for these efficiencies by assuming what efficiencies will satisfy the decrease in the coefficient, as follows:

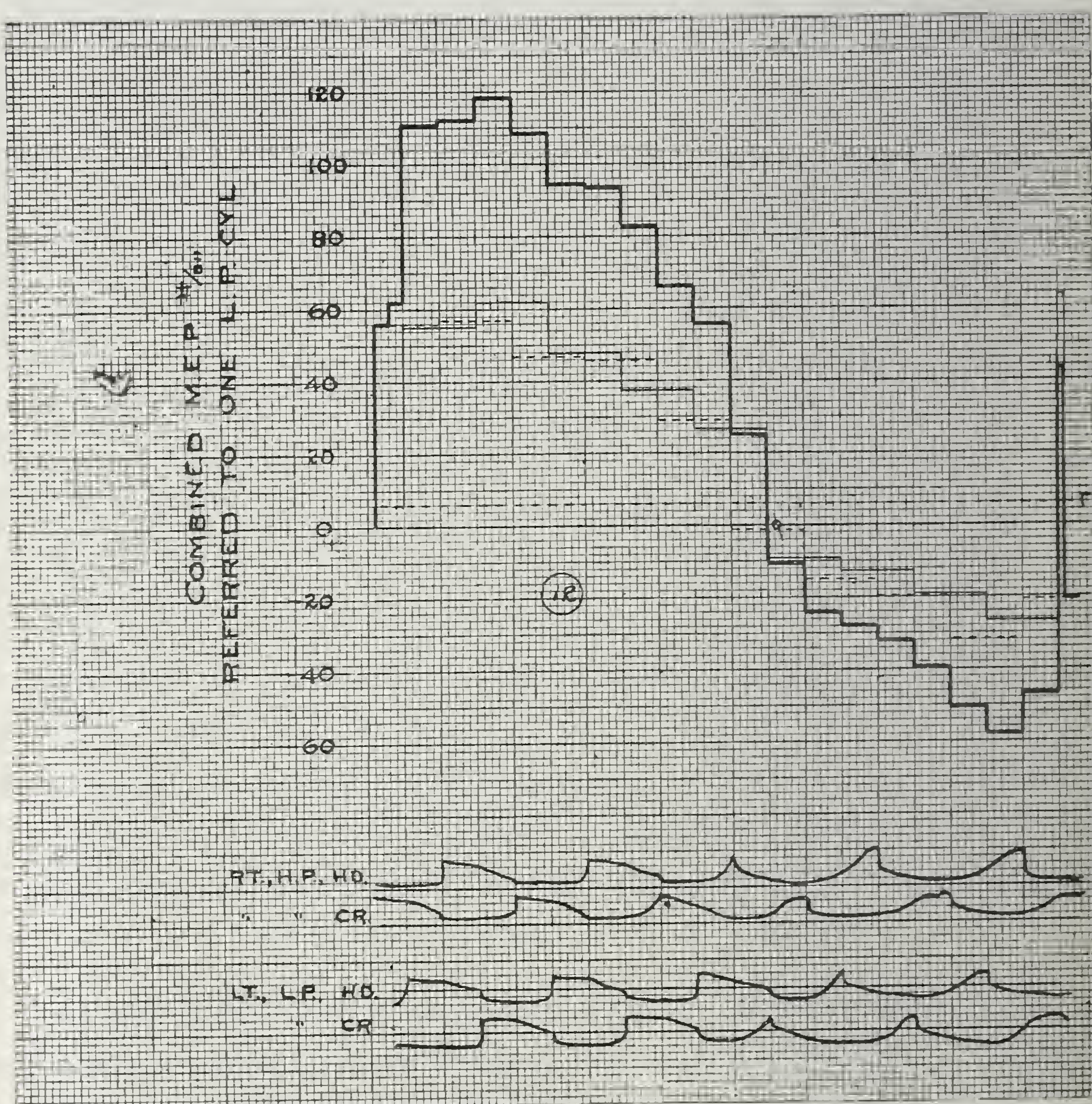


Fig. 43. M. E. P. Curve, Pass No. 12.

For convenience, taking the rough pinions and spindles as having the friction, E_r, and the cut pinions and spindles with the friction, E_c, we have

$$\frac{E_r}{E_c} = \frac{14200}{12000} = 1.183$$

According to Dr. Puppe's tests (*Stahl und Eisen,* April and May, 1911) we should expect even a greater ratio.

Or, not using the coefficient, the ratios of net work, foot pounds per ton of steel rolled, is

$$\frac{W_r}{W_c} = \frac{17\,900\,000}{15\,400\,000} = 1.16$$

It would be difficult to say how much greater than 18 percent the cut pinions and spindles would show were it not for the fact that at present they have to be charged for the ad-

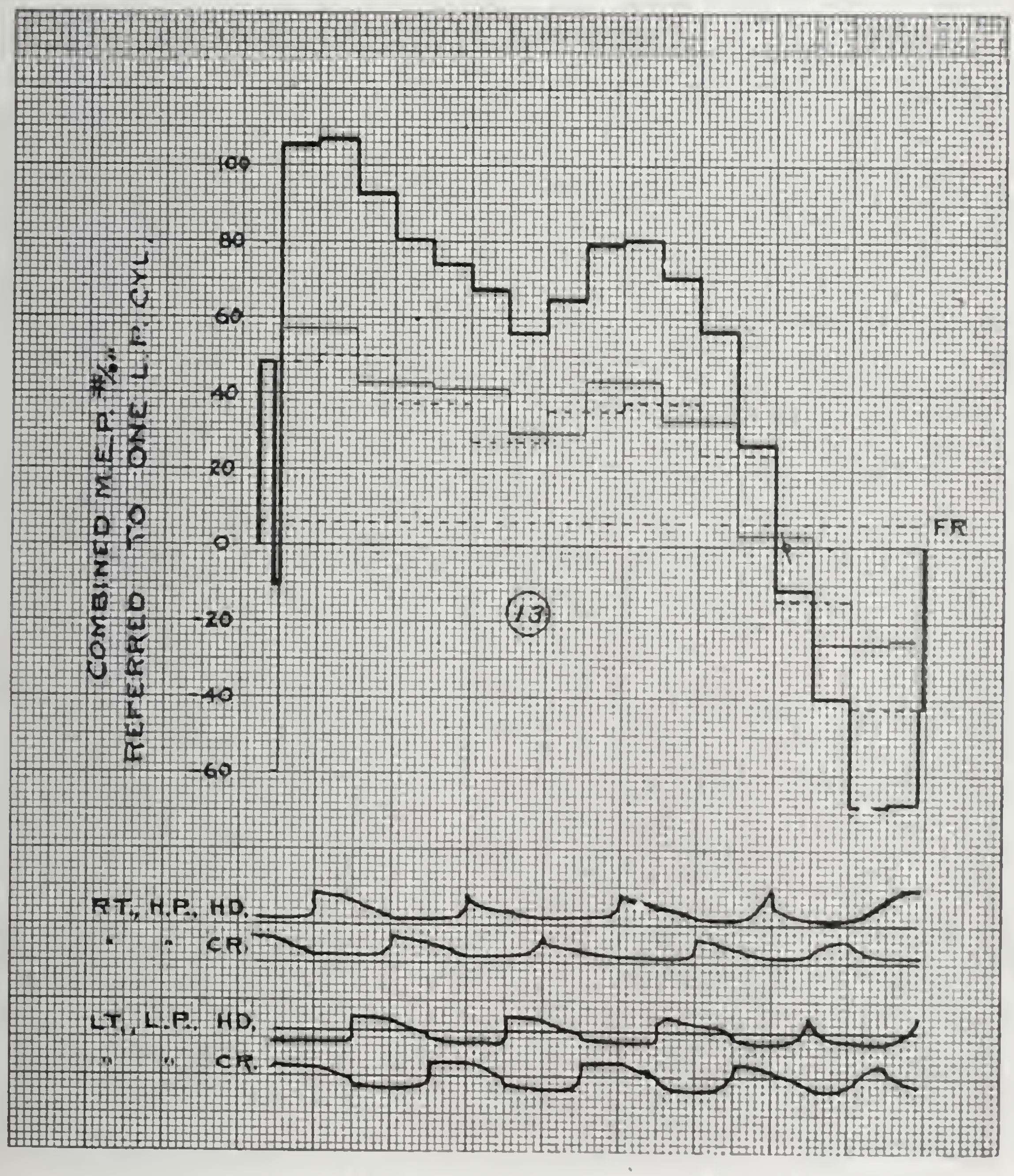


Fig. 44. M. E. P. Curve, Pass No. 13.

vantage that their engine had in Corliss valves and continuous running and a large fly wheel.

In measuring the steam consumption from the indicator cards, it was first thought that only the steam of the working cards should be charged against the engine. Such a measurement, taken just before release on the low pressure cards in the usual way, showed 333 pounds of dry steam per gross ton of steel rolled.

It appeared therefore that there should be a steam charge for plugging. In order to better understand the cards, two combined cards were made, one representing all the working and one all the plugging cards. The former shown in Fig. 47 is a typical compound engine card, the latter shown in Fig. 48 is a form of card resembling somewhat that of a compound compressor.

The number of revolutions for each combined card was found by taking half the total strokes of the positive areas and negative areas respectively of the M. E. P. curve. A tiny circle

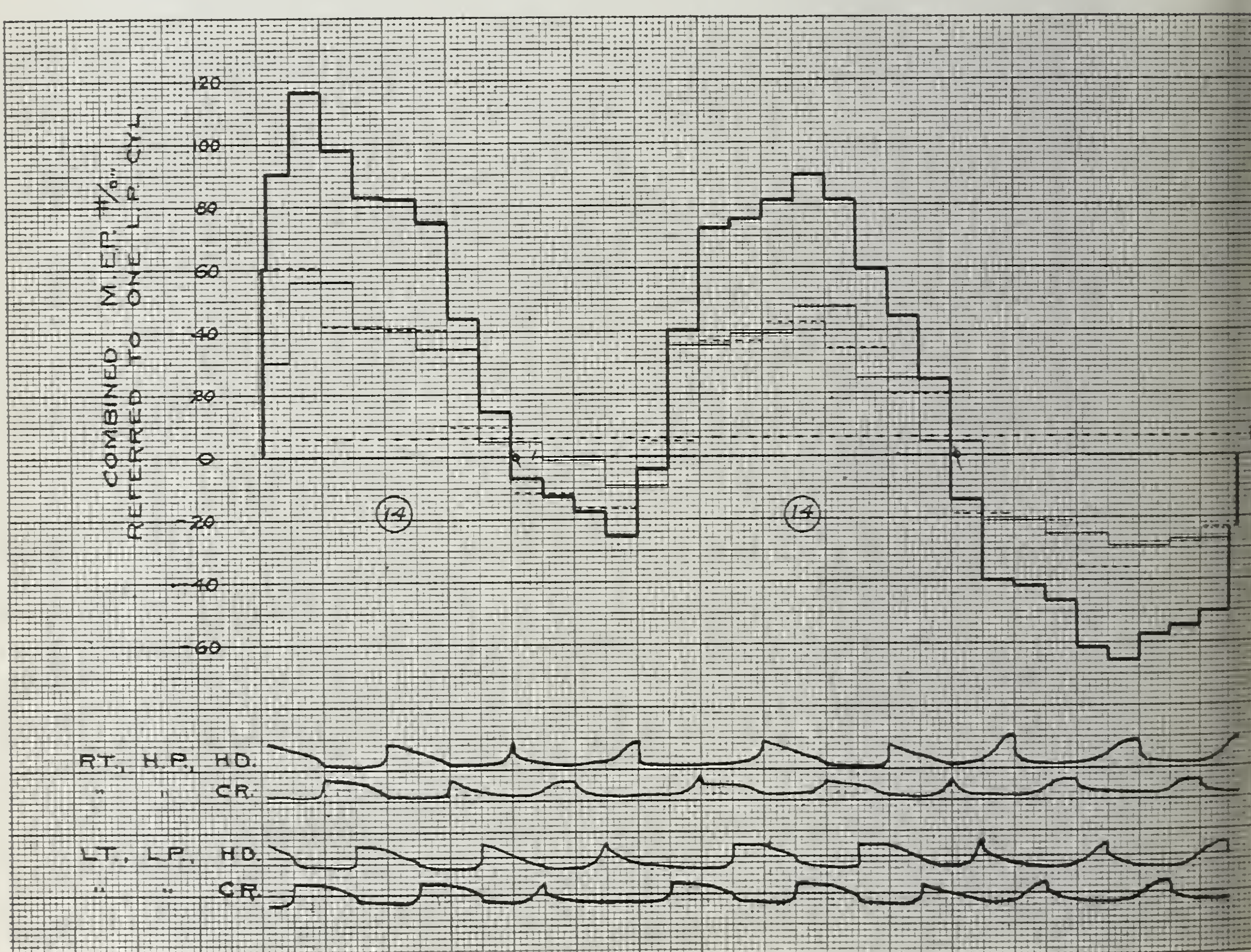


Fig. 45. M. E. P. Curve, Pass No. 14.

is shown on the zero line of the M. E. P. curve to show the point of division between the working strokes and the plugging strokes.

The combined cards were tested against the M. E. P. curve for work as follows:

Working Card

Area of H. P. card, square inches	5.015
Area of L. P. card, square inches	4.215
Total area of both cards, square inches	9.230
Calculated M. E. P. pounds per sq. in.	36.92
Work per revolution (whole engine) ft. lb.	1 597 000
Number of strokes	69.5
Total positive work, foot pounds	111 000 000

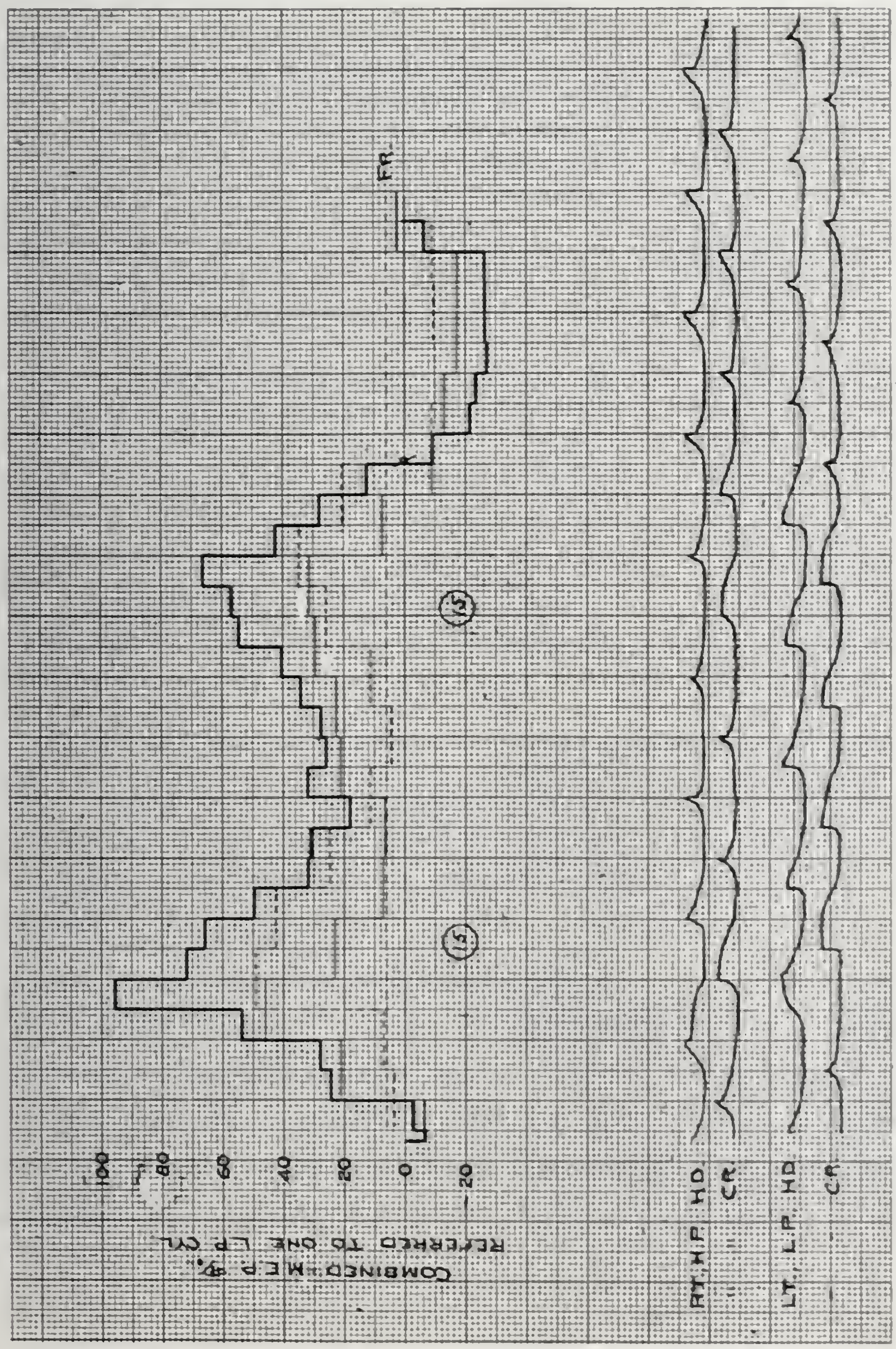


Fig. 46. M. E. P. Curve, Pass No. 15.

Plugging Card

Area of H. P. card, square inches	3.07
Area of L. P. card, square inches	1.42
Total area of both cards, square inches	4.49
Calculated M. E. P., pounds per sq. in.	17.84
Work per revolution (whole engine) ft. lb.	774 000
Number of strokes	45.5
Total negative work, ft. lb.	35 200.000

Therefore, the combined work of rolling and the work of friction is 75 800 000 foot pounds. The difference between this value and the value obtained from the M. E. P. curve is about 2 percent.

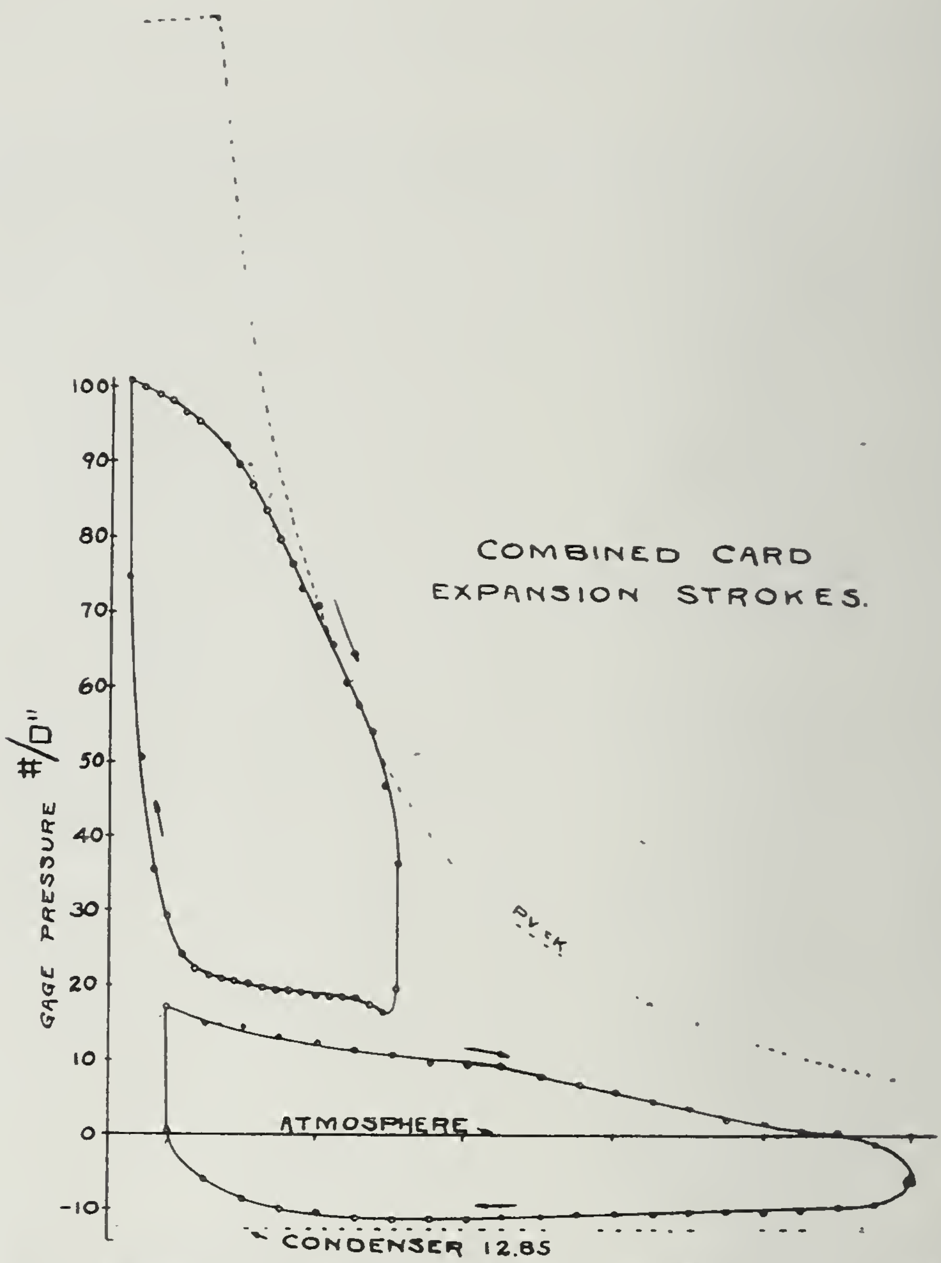


Fig. 47. Combined Indicator Card for Working Strokes.

On the combined cards at several points are shown in dots the lines for $P V = K$. In the working card the low pressure card shows a loss. This loss may be due to three things: First, some steam used in the high pressure card for working is used

by the low pressure cylinder expansively during plugging; second, some steam is condensed in the receiver during the plugging period; and third, the high pressure cylinder withdraws some steam from the receiver during plugging.

Because of these losses it is better to measure the steam from the high pressure card. The steam to be charged is measured as follows:

	Pounds
Dry Steam.	
A. Just before release in high pressure cylinder allowing for clearance	1060
B. Clearance volume of high pressure cylinder for plugging stroke	28
C. Steam used in plugging, 437 lb., not charged (measured on h. p. card)	
Condensation:	
D. Condensation from A @ 25%	267
E. Condensation from B @ 25%	7
F. Condensation from C @ 25%	109
Total dry steam per ingot is	1088
Total condensation per ingot is	383
Total steam charged per ingot is	1471
Total steam charged per gross ton of steel	575

We can arrive at the same figure in a somewhat different way:

Number of working revolutions 69.5 ÷ 2 =	34.75
Number of plugging revolutions 45.5 ÷ 2 =	22.75
Condensation (from *A*) per revolution	7.70
G...Condensation for 57.5 revolutions	443.00
Total steam (equals *A* plus *B* plus *G*)	1531.00
Steam per gross ton	597.00

In other words, charging the engine at 25 percent condensation during the working revolutions on the dry steam used, and the same amount per revolution during plugging and adding in the clearance steam lost during plugging, we arrive at substantially the same figure.

Referring to the test of the International Harvester Company's reversing engine, made by Mr. Gasche*, we find for a non-condensing simple twin engine (42 in. by 60 in.) a steam consumption of 1200 pounds per gross ton of steel rolled. The engine exhausted into a regenerator from which it went to a low

*See *Power,* June, 1907.

pressure turbine and thence to a condenser. The dry steam as measured from the cards had to be increased by 48 percent to allow for the condensation as shown by the condenser test. The 13th pass (7 in. by 8¼ in.) corresponds with the 9th pass of the three-high mill and the net work for rolling up to and including that pass was 47 049 000 foot pounds. The weight of the ingot was 2.45 gross tons, and there was a net work done of 19 200 000 foot pounds per gross ton of steel rolled.

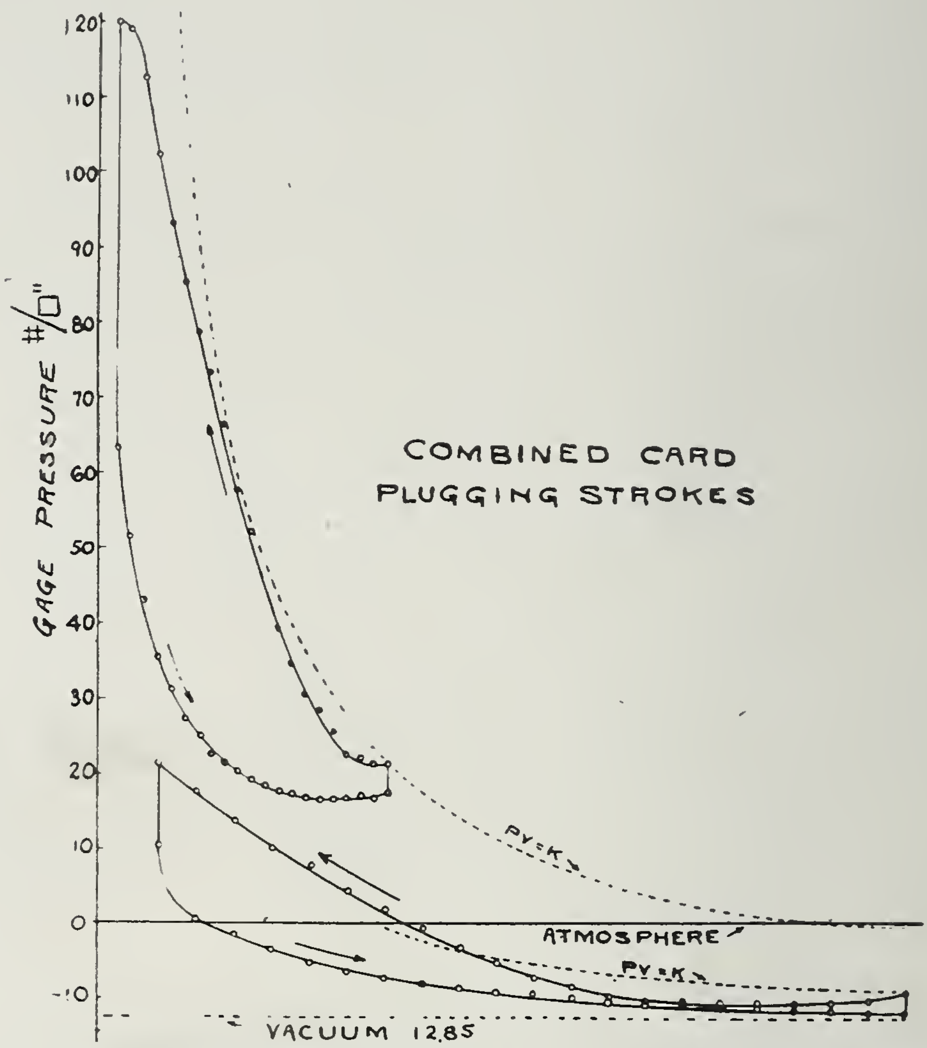


Fig. 48. Combined Indicator Card for Plugging Strokes.

The 17th pass (5 in. by 6⅛ in.) corresponds fairly well with our present test and the net work up to and including this pass is 66 209 000 foot-pounds per ingot or 27 000 000 foot-pounds per ton. This test having been made early in 1907, it is likely that the mill has rough cast pinions and spindles. If so, the ratio between the above and the net work per ton for the present test should correspond with the ratio otbained by the comparison with the three-high mill. We have:

$$\frac{W_r}{W_c} = \frac{27\,000\,000}{22\,800\,000} = 1.182$$

which is practically the same as found in the first comparison.

The three-high mill used 276 pounds of dry steam per ton of steel rolled, and adding 25 percent for condensation, we have 345 pounds of wet steam per ton of steel rolled. When we consider that the two-high mill engine expends 33 percent of its work upon acceleration and retardation of the moving parts, and when we correct its steam accordingly, we get (575 x 2-3=) 383 pounds per ton of steel rolled. This is still not quite so low as the three-high mill engine, probably due to the fact that the three-high mill is faster.

In conclusion, it appears that this engine and mill are rolling blooms with a low net work expenditure chiefly due to cut pinions and machined spindles; and the steam consumption per ton of steel apparently corresponds with that of other two-high mill engines. As compared with three-high mill engines. the steam consumption appears to be 33 percent high, half of which is due to excessive work of starting and half due to excessive plugging.

The Author: I wish to take this opportunity to thank Mr. Coryell for the work which he has done in calculating the observations taken when rolling one ingot from our mill.

In the main, the results as found by him check with those determined by the calculation of other sets of observations.

His Fig. 32, showing the position of the pistons of the engine at each reversal, is interesting, although it does not appear to give any additional information over that exhibited by the M. E. P. curve as plotted by us.

The plotting of the M. E. P. of each pass on a separate sheet does not seem to be necessary, and I believe does not represent as clearly the operation of the mill for an entire ingot as is the case when the total curve is plotted on one sheet—as we do.

Plotting the M. E. P. curve in square sections instead of by means of a point to point curve, we do not feel makes as satisfactory a representation of what is actually taking place as is done by our method. The error introduced by the area of

the triangles as mentioned by Mr. Coryell, we feel to be negligibly small.

It is true that Mr. Coryell is able to plot the curves to the actual point of reversal by making each pass on a separate sheet, but the error, due to plotting this to the nearest ⅛ revolution, as is our practice, is negligible.

The combined cards as plotted by Mr. Coryell are certainly of considerable interest, but we do not feel that they are of sufficient value to warrant the tremendous amount of work involved in obtaining them. It is exceedingly interesting to note how closely work determined from these cards checks with the work determined from the total M. E. P. curve.

Referring to the combined cards of the plugging strokes, as plotted by him, we are at a loss to see how the compression curve can fall below the adiabatic. This is probably due to the drawing of the adiabatic curve from the point at the end of the stroke in each case. These points are exceedingly difficult to accurately locate, and I believe that there is probably a considerable error encountered in determining these. If the adiabatic had been drawn from a point 2 or 3 removed from the end of the stroke, it would probably have been more accurate, although any point located by measurement from such a large number of indicator cards would probably be subject to a considerable error.

ADDENDA.

Mr. W. C. Coryell: Since writing a discussion of Mr. Nibecker's paper the writer has tested the new blooming mill engine at the Brier Hill Steel Company's plant. As the data brings out some interesting points it may be of value to engineers if presented.

As the engine and mill are quite fully described in the *Iron Age* and the *Iron Trade Review* of April 2, 1914, it is not necessary to give a full description. Let it suffice to say that the mill is 40 in., two-high, and reversing; and the engine is twin tandem compound 44 in. and 76 in. by 60 in., non-condensing. The special features of interest are the Kennedy machined spindle, the Walschaert valve gear, and the special engine control which will be mentioned later.

Figure 49 shows the mill and pulpit, and Fig. 50 shows the engine. The latter is at present exhausting to a heater, although it is proportioned for condensing.

The test was made with continuous indicators, four being of the open diagram type on the high pressure cylinders, and four of the closed diagram type on the low pressure cylinders. Several perfect sets of cards were obtained, but the data from only one is given here. The cards were traced, partly for permanent record and partly for the greater ease of reference.

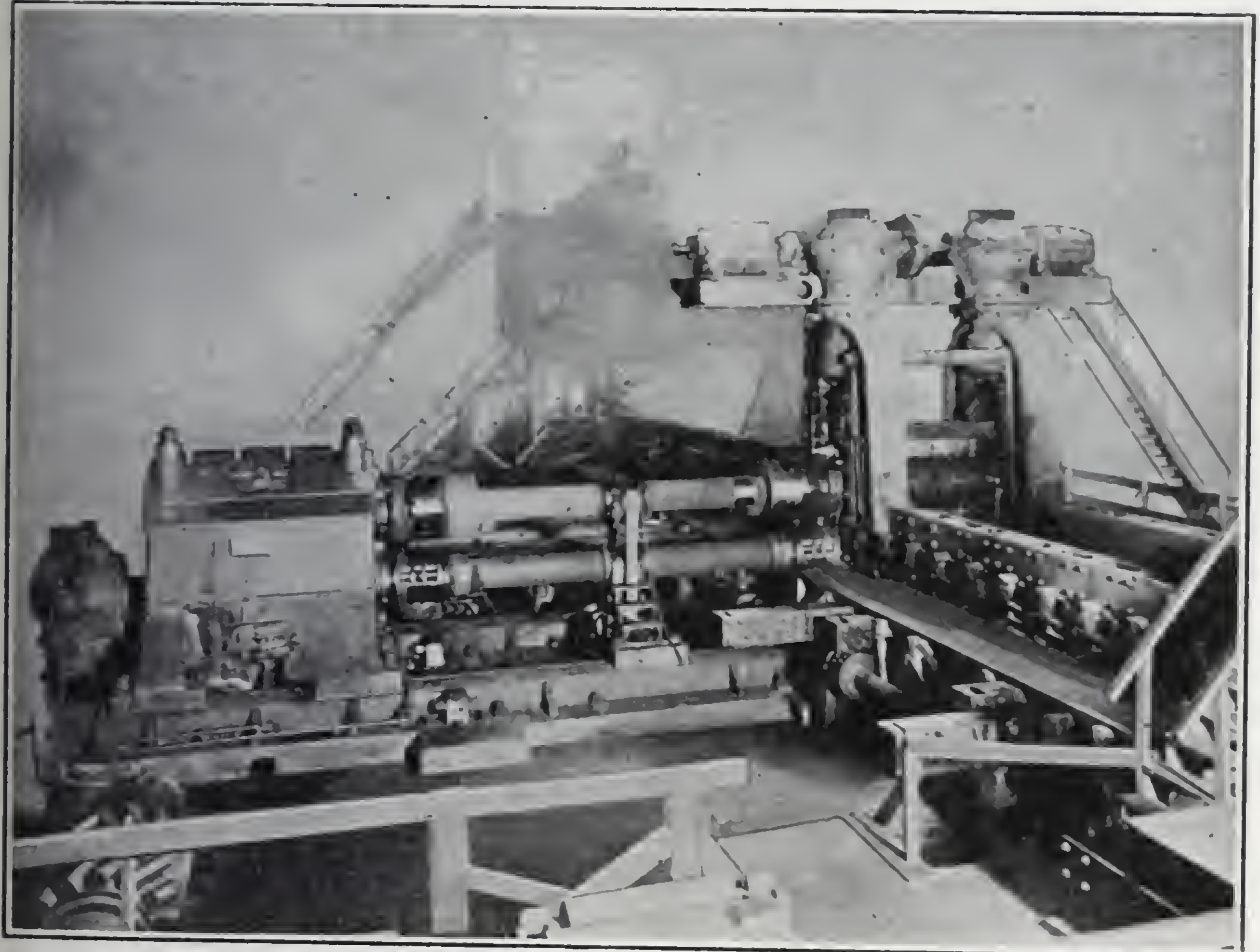


Fig. 49. Mill and Pulpit at the Brier Hill Steel Company's Works.

The closed diagrams were opened out in tracing. This produces cards with two lengths varying alternately with each other. This does not introduce any error, but care must be taken in figuring M.E.P. to use the correct lengths. A typical complete set of cards for pass 10 is shown in Fig. 51.

The springs used in this test were

Right and Left High Pressure crank, 100 lb.
Right and Left High Pressure head, 110 lb.
All Low Pressures, 20 lb.

The engine and mill were running under normal conditions, without any unusual effort to produce fine results. The ingots, the day of the test, were cold ones, reheated. This was the cause of some delay in the mill, and the cause of some complaint by the mill men on account of the cold steel. Pyrometer readings were taken with a new instrument, but they are quite evidently in error and are, therefore, thrown out.

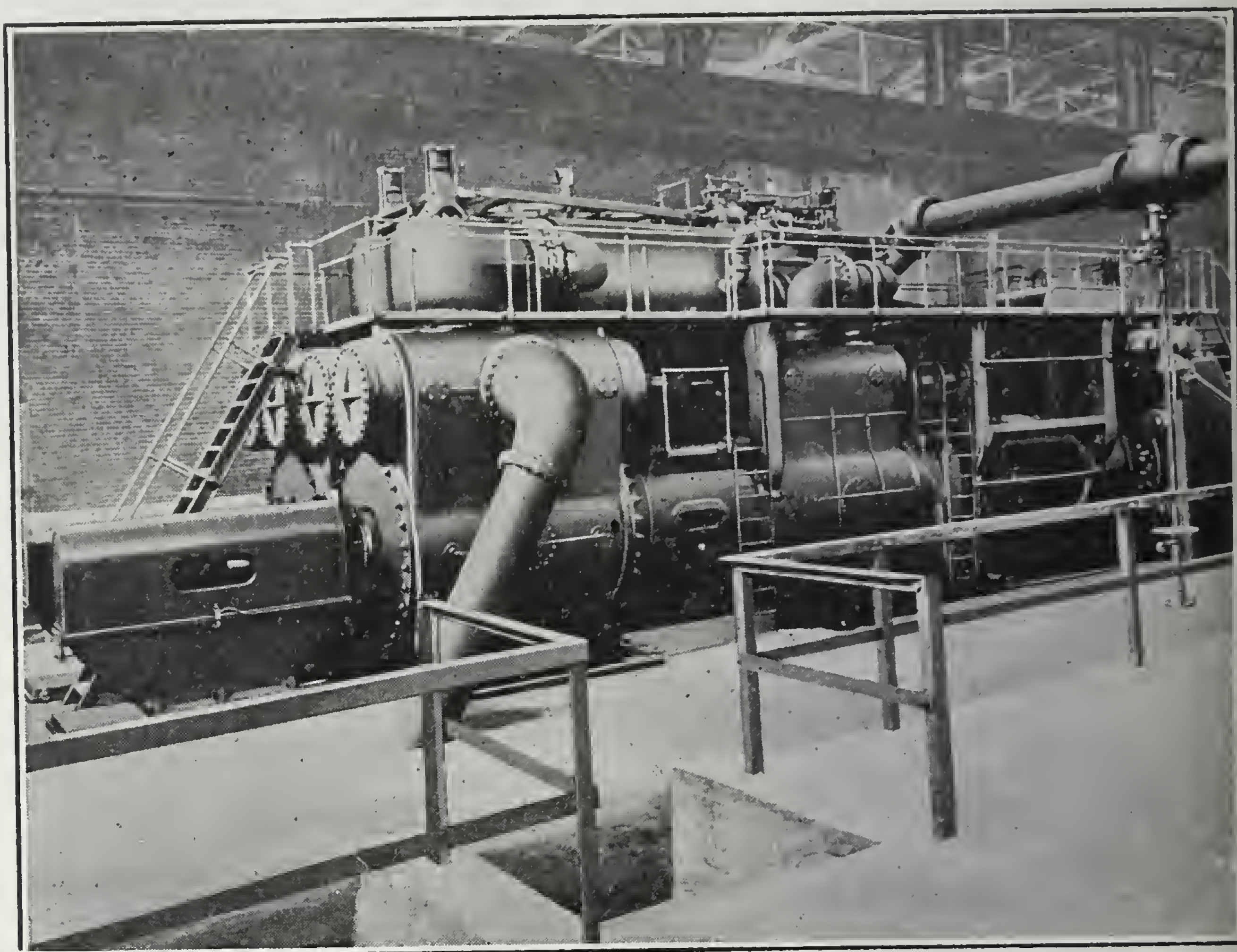


Fig. 50. The Brier Hill Steel Company's Engine.

The method followed in working up the test is the same that was followed in working up the Sheet and Tube data. Therefore, the results are comparable, except for the facts that one engine exhausts to a condenser and the other to a heater.

Between this test and that of the Sheet and Tube engine there are several points of similarity, as should be expected between two good modern engines. Also, there are several points of difference, which will be presented.

The steam at the engine receiver was at about 160 pounds pressure and had about 10 deg. Fahr. superheat.

The tendency of reversing engines to stop at definite points

with one crank or the other just before dead center, occurs with this engine, as is usually the case with reversing engines. This is the position of great resistance due to compression.

This engine has a special controlling device. The high and low pressure cylinders each have their own throttle valves. These and the links are under the control of two interconnected levers. When the engine is reversed the steam can be shut off from all cylinders simultaneously, or nearly so. Several advantages occur from this. First, the steam, being all shut off, is saved; second, due to this saving, a corresponding saving is made in plugging; third, the receiver pressure being kept up, gives the high pressure plugging card a higher point from which to start plugging and it also has a supply of steam ready for the low pressure cylinder at the beginning of the next pass; fourth, the total number of revolutions per pass is kept down; and, fifth, the low pressure cylinder, not having steam, helps plugging with its *negative M.E.P.,* when non-condensing. In other words, the saving is cumulative.

The M.E.P. for all cylinders is worked up and referred to one low pressure cylinder, the cylinder ratio being 3.06. The combined M.E.P. for pass 10 is shown in Fig. 52. These curves are much like those submitted in the writer's discussion for the Sheet and Tube engine, except the positive M.E.P. is not so high; the negative M.E.P. is not so low; and the ratio of negative area to positive area is much less.

On these curves a small circle on the zero line shows the ending of the positive work and the beginning of the negative work.

The friction M.E.P. was obtained by running the engine at 48 r. p. m. The cards were so uniform in size that twelve revolutions on the same card showed a narrow line clear around the card. The M.E.P. referred to one low pressure cylinder is 5.5 lbs. per sq. in.

The steam upon starting the engine is throttled and used with long cut-off, but the pressure builds up rapidly to normal pressure with decreasing cut-off, after which the cut-off is lengthened to obtain more power. Very little work is done under the condition of throttling, as the only time when this is

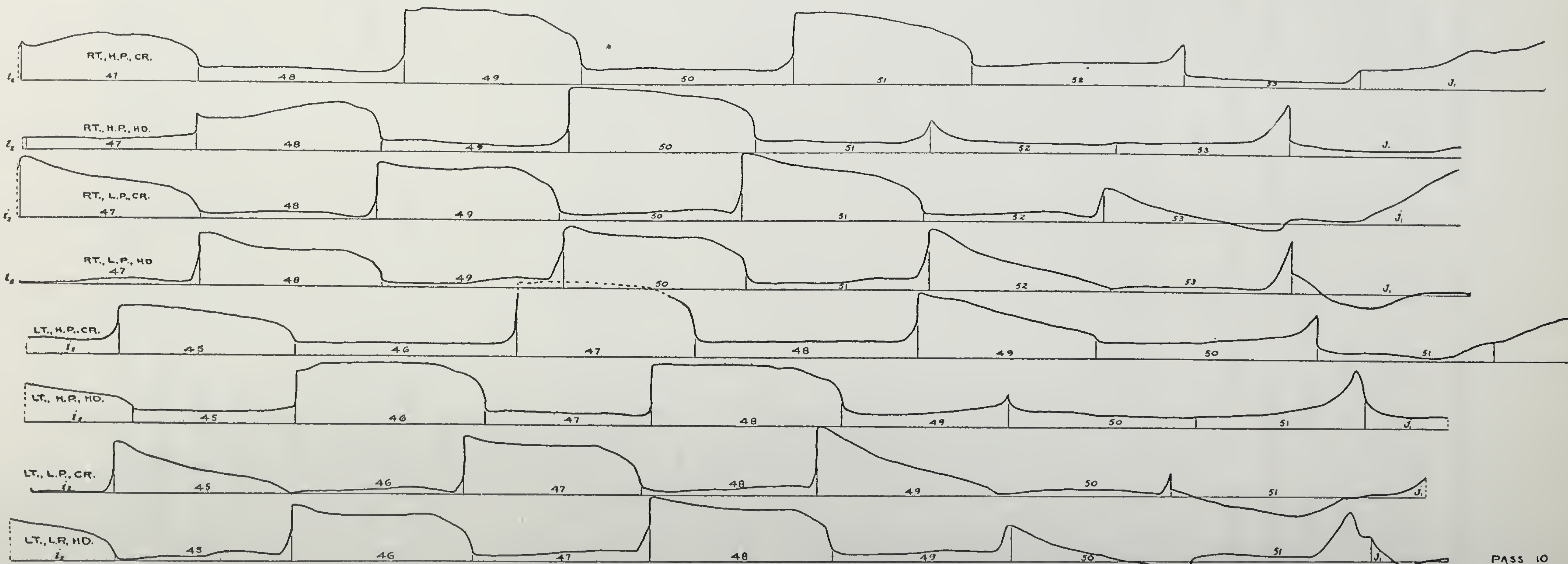


Fig. 51. Indicator Cards from the Brier Hill Steel Company's Engine.

required is upon starting. Figure 53 shows an ideal series of cards starting with engine at rest, card 1, and ending with maximum load at card 10. In practice, however, we do not necessarily get this series as the mechanism may pass rapidly through one or all of the successive positions.

Comparing these M.E.P. curves with those submitted with the writer's discussion of the Sheet & Tube Company's test we obtain the following:

	Sheet & Tube Engine	Brier Hill Engine
Total number of strokes per ingot........	115	94
Number of plugging strokes per ingot..	45.5	30.6
Maximum M. E. P. (referred to one l. p. cylinder, lb. per sq. in.)		
Working	127	101
Plugging	79	39

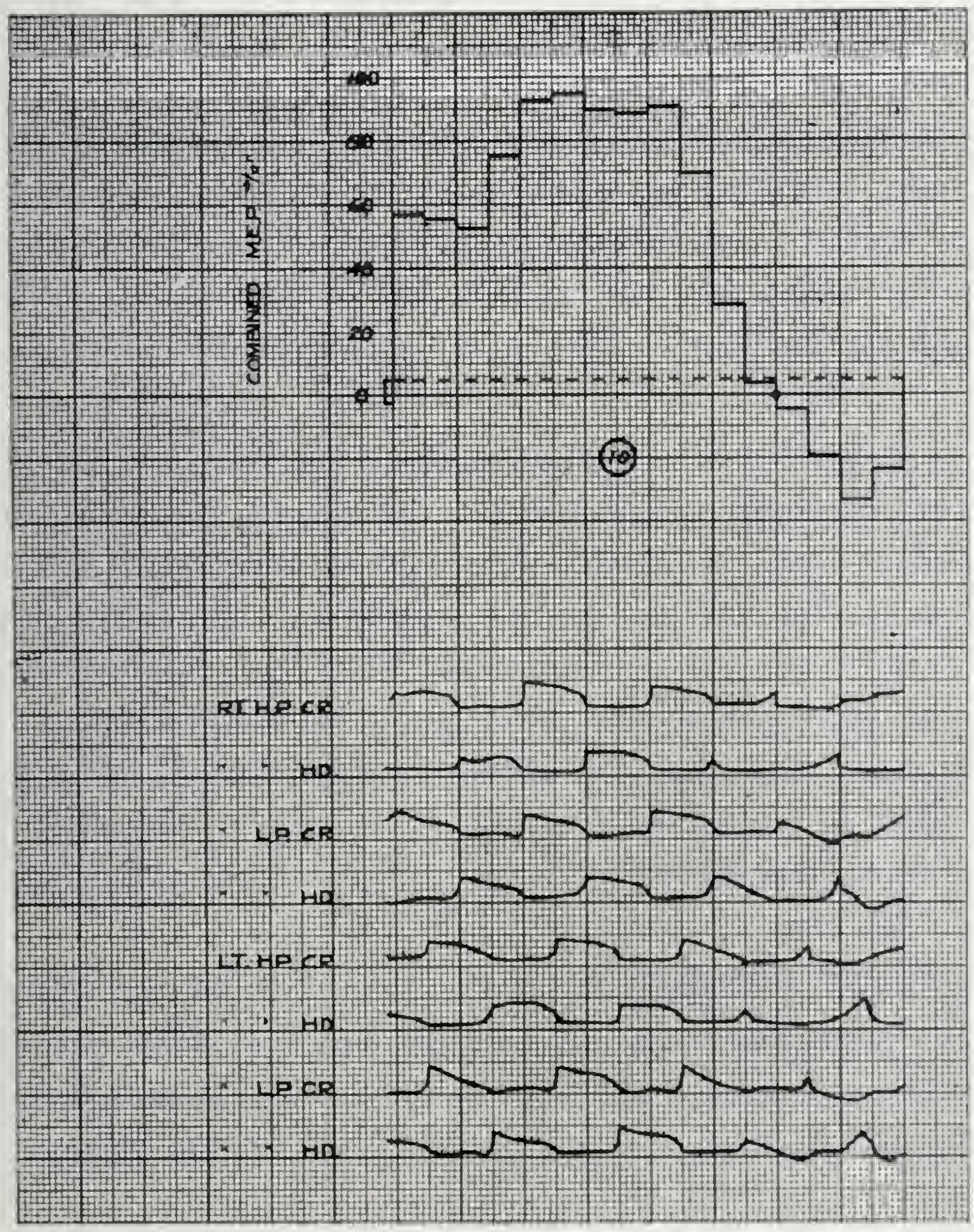


Fig. 52. M. E. P. Curve for Pass No. 10, Brier Hill Steel Company's Engine.

During plugging the low pressure cylinder often operates with a vacuum M.E.P. of five to six pounds. This negative work has a powerful effect in aiding the plugging operation on the opposite side of the piston. For example, stroke No. 51 on the left low pressure crank card, pass 10, shows a negative M.E.P. of only three pounds, yet this one cylinder aided in stopping the engine to the extent of 72,000 feet pounds more than it would have done if the M.E.P. had been zero pounds.

The average time per revolution has been increased, but it must be remembered that more time can be had for useful work when less useless work is done. That is what this engine is doing. There has been no occasion to do fast rolling, as the plant has only about half enough open hearth furnace capacity to keep the mill busy; but there are occasionally periods in which they roll fifty ingots per hour or one a minute. No records have been attempted.

The acceleration of the engine and the retardation were too rapid and lasted too short a time, to be taken with a stop watch. An idea can be obtained of the retardation upon seeing the mill operate. It frequently occurs, when the engine stops, that the piece leaving the rolls is left within a few inches, to a foot, beyond the rolls. The time of rolling is shown in Table No. 12.

The gauge for the screwdown reads on the "bull-head" pass, and was found immediately after the test to be uniformly one-eighth of an inch too small. The size of the pass is determined from the reading of the gauge wheel, but, since the spread is not controlled the exact sizes of the passes are not known. The piece was held before the first pass for length measurement, and after the last pass for section measurement. The drawing of the rolls is shown in Fig. 54. Grooves *A*, *B*, and *C*, were used. The actual gauge readings and order of rolling are shown in Table No. 12.

The work is derived from the M.E.P. curve in which ordinates are pressures, and abscissa are strokes. The product, an area, represents work. In these diagrams one square inch equals forty pounds for two strokes, or 2 092 800 ft. lbs. of work. The

summary of work per pass and the distribution of that work is shown in Table No. 13.

TABLE NO. 12. TEST DATA.

Pass. No.	Time of Entering Pass-Sec.	Gage Reading	Groove	Manip-ulation
1	0.	18.5	A	
2	3.5	16.5	"	
3	9.7	17.5	"	Turn
4	13.	15.5	"	
5	17.2	13.75	"	
6	20.8	12.00	"	
7	27.2	12.00	B	Turn
8	31.8	9.75	"	
9	37.0	7.75	"	Turn
10	42.0	5.25	"	
11	50.0	7.75	C	Turn
12	55.0	6.125	"	
13	62.0	6.75	A	Turn
14	67.7	6.75	"	
15.	75.8	5.125	C	Turn
Leaving Press	79.3			

TABLE NO. 13.
DISTRIBUTION OF WORK AS SHOWN BY M. E. P. CURVE.

Pass No.	Total Positive Work Ft. Lbs.	Total Negative Work Ft. Lbs.	Rolling & Friction Work Ft. Lbs.	Friction Work Ft. Lbs.	Net Rolling Work Ft. Lbs.
1	3 510 000	815 000	2 695 000	557 000	2 138 000
2	5 330 000	1 773 000	3 557 000	738 000	2 819 000
3	2 200 000	732 000	1 468 000	616 000	852 000
4	4 140 000	502 000	3 638 000	508 000	3 130 000
5	4 930 000	523 000	4 407 000	628 000	3 779 000
6	5 000 000	920 000	4 080 000	641 000	3 439 000
7	6 930 000	711 000	6 219 000	713 000	5 506 000
8	6 900 000	1 125 000	5 775 000	713 000	5 062 000
9	9 000 000	711 000	8 289 000	872 000	7 417 000
10	10 350 000	1 021 000	9 329 000	980 000	8 349 000
11	9 070 000	167 000	8 903 000	931 000	7 972 000
12	7 540 000	1 261 000	6 279 000	920 000	5 359 000
13	5 680 000	482 000	5 198 000	1 065 000	4 133 000
14	4 600 000	1 960 000	2 640 000	1 100 000	1 540 000
15	7 905 000	0 000 000	7 905 000	1 065 000	6 840 000
Total	93 085 000	12 703 000	80 382 000	12 047 000	68 335 000

93 085 000 = 100% = Total Work
12 047 000 = 13.0% = Friction
12 703 000 = 13.6% Negative Work
68 335 000 = 73.4% Net Work to Roll

Comparing this data with the Sheet & Tube Company test we find a marked difference, thus:

	Sheet & Tube Engine	Brier Hill Engine
Total work expended per ingot, ft. lbs....	110 000 000	93 000 000
Distribution, % to friction	13.8	13.0
% to plugging	33.3	13.6
% to rolling piece (net)....	52.9	73.4

The work of friction, as should be expected, remains about the same, but the engine having the control and low pressure throttle valves requires less work for plugging, and hence can put that much additional work into the piece being rolled.

The work of rolling and the coefficient are shown by the following calculations:

Average size of ingot, inches...........................	18 by 20
Sectional area of ingot, sq. in. (A)...................	360
Length of ingot, feet (L)............................	5.63
Weight of ingot, gross tons...........................	2.8
Size of finished piece, inches..........................	7.06 by 7.25
Sectional area of same, sq. in. (a)...................	51
Time of rolling, seconds..............................	80
Ratio of sectional areas (A divided by a).............	7.07
Hyperbolic logarithm of (A divided by a).............	1.956
Net work to roll ingot, foot pounds.....................	68,335,000
Coefficient, $C = \dfrac{\text{foot pounds}}{\text{A. L. Hyp. log. } (A \div a)}$............	17,300

This high coefficient is due to the reheated ingots, not being sufficiently heated at the center.

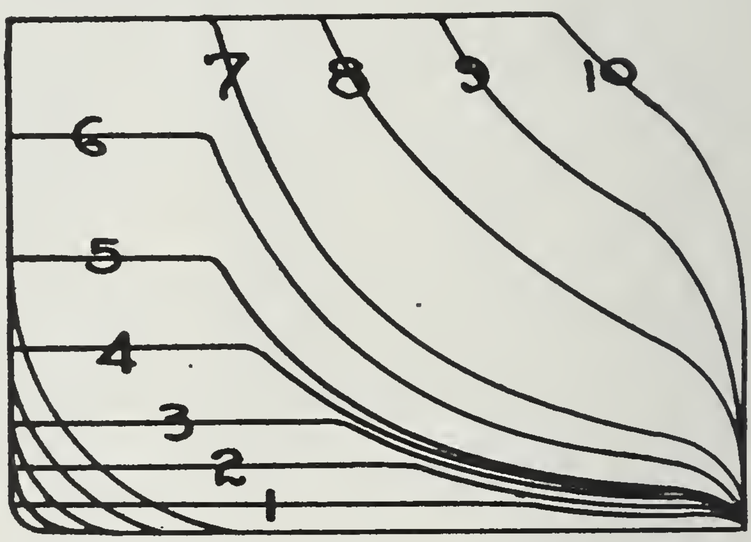


Fig. 53. Ideal Series of Indicator Cards for the Brier Hill Steel Company's Engine, starting from rest.

No steam meter tests were taken as they are subject to too many possibilities for error when applied to reversing engines, to make them reliable. The error due to quality of steam can be corrected for and possibly the errors due to inertia of the measuring fluid (usually mercury) offset each other. But grant that these difficulties are overcome, let us consider the measurement of the curve itself. In reversing engines the velocity of the steam through the meter varies within a period of a few

seconds, from zero feet per second to several hundred feet per second as a maximum and then drops back to zero again. The formula upon which these instruments are usually based is $V = \sqrt{2gh}$. Usually when the curve is obtained, it is planimetered and the area found is multiplied by a constant to determine the weight of steam. In other words, the readings are averaged first and the square root of the average is taken afterward, while strictly the square root of each ordinate should be taken and all the square roots averaged. Take a concrete case in which the readings are 0, 25, 49, 16, and 0, the square root of the average of this series is 4.2, while the average of the square roots is 3.2.

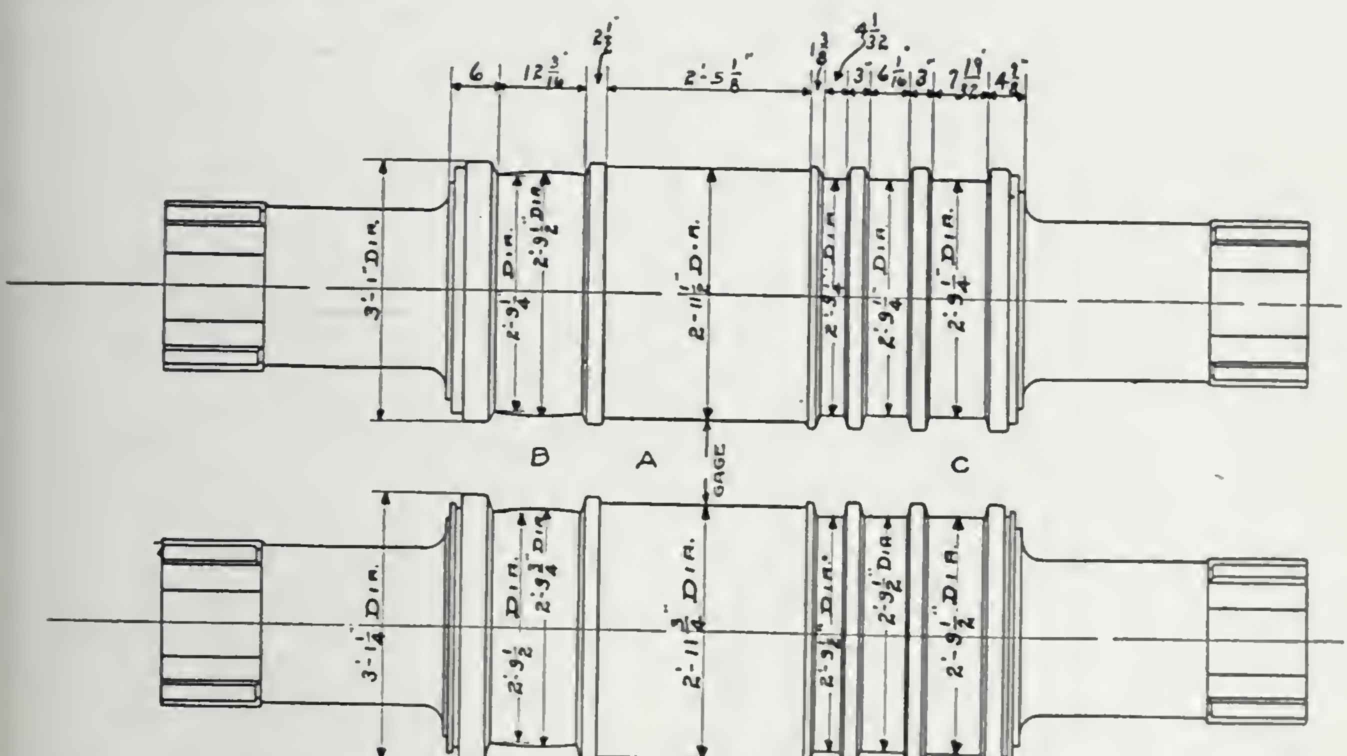


Fig. 54. Roll Dimensions for Brier Hill Steel Company's Mill.

This difficulty arises with all Venturi meters, Pitot tubes, throttling discs, and weirs, when the flow is very irregular. A check could not be run on the feed water heater as some of the steam escaped to free exhaust. Condenser tests are reliable when the weir is properly constructed and when surging is prevented in the hot well. We determined therefore to depend upon the steam indicator and the combined card.

The steam consumption of a reversing engine cannot be figured by first measuring the steam from the cards individually, then, combining the steam, and lastly, allowing for condensation. The cards themselves show very plainly that steam once

getting into the cylinder rarely gets back into the steam chest. The steam chest pressure on the Sheet & Tube engine was about 150 lb. and that on the Brier Hill engine about 160 lb. Some cards at the former rose to the necessary pressure and exhausted into the steam chest whenever the throttle was open; and many of them did not attain the necessary pressure. But at the latter plant the highest plugging card was 125 lb. pressure.

A reversing engine is really a steam engine and a *steam compressor,* the two operations occurring alternately in the same cylinder. Now, if these operations were occurring con-

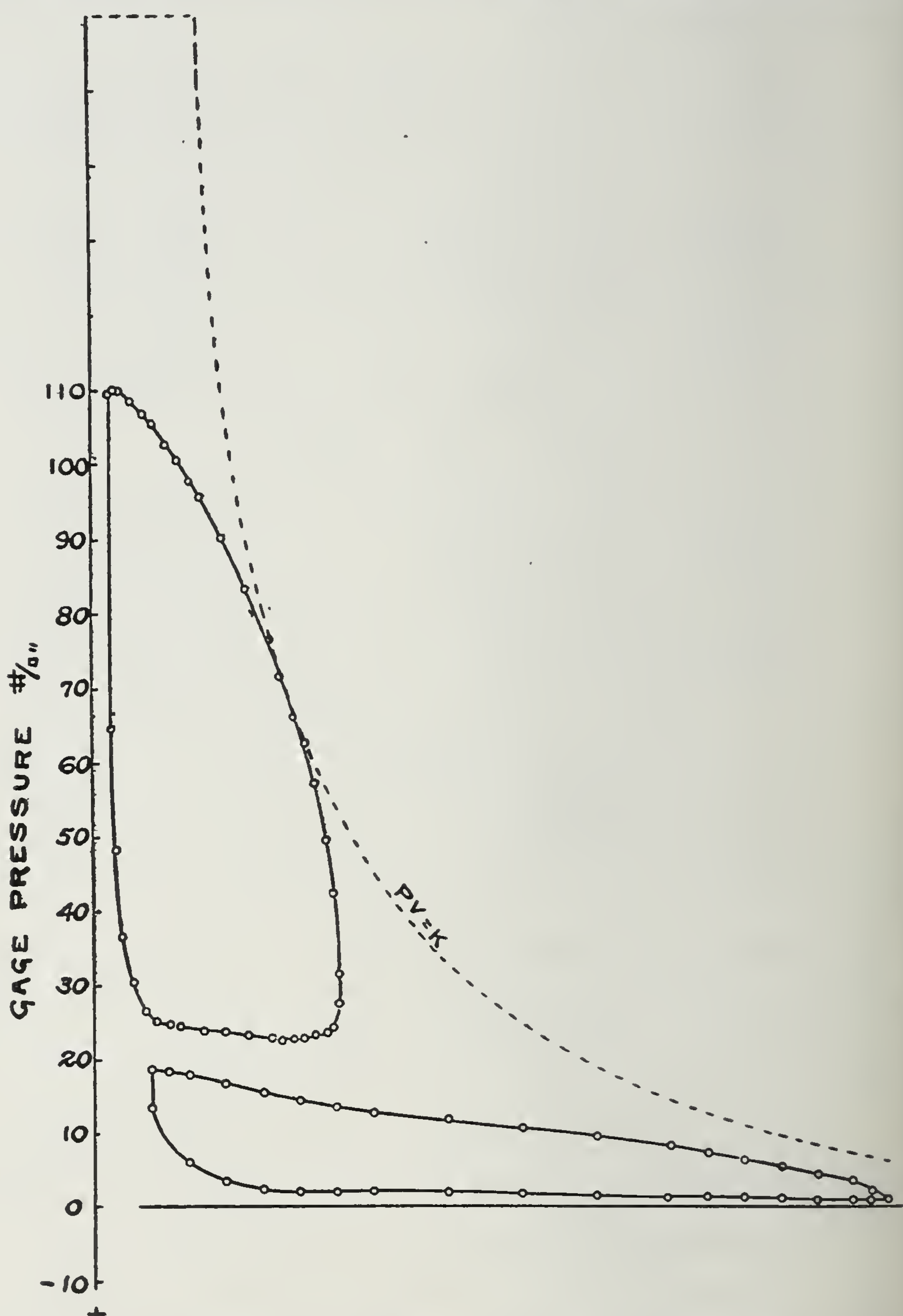


Fig. 55. Combined Indicator Card for Working Strokes, Brier Hill Steel Company's Engine.

tinuously in different cylinders, no engineer would omit charging both operations for condensation. Then why omit the charge when the two operations occur alternately in the same cylinder, as was done in the principal paper?

In Figs 55 and 56 are shown the combined cards, the former showing the working card and the latter the plugging card. These cards are the average of every card during the entire rolling of the ingot. For instance, the high pressure expansion line of the working card contains the average of all the expansion lines of the high pressure working cards. This is also the case with the other portions of the combined cards. No

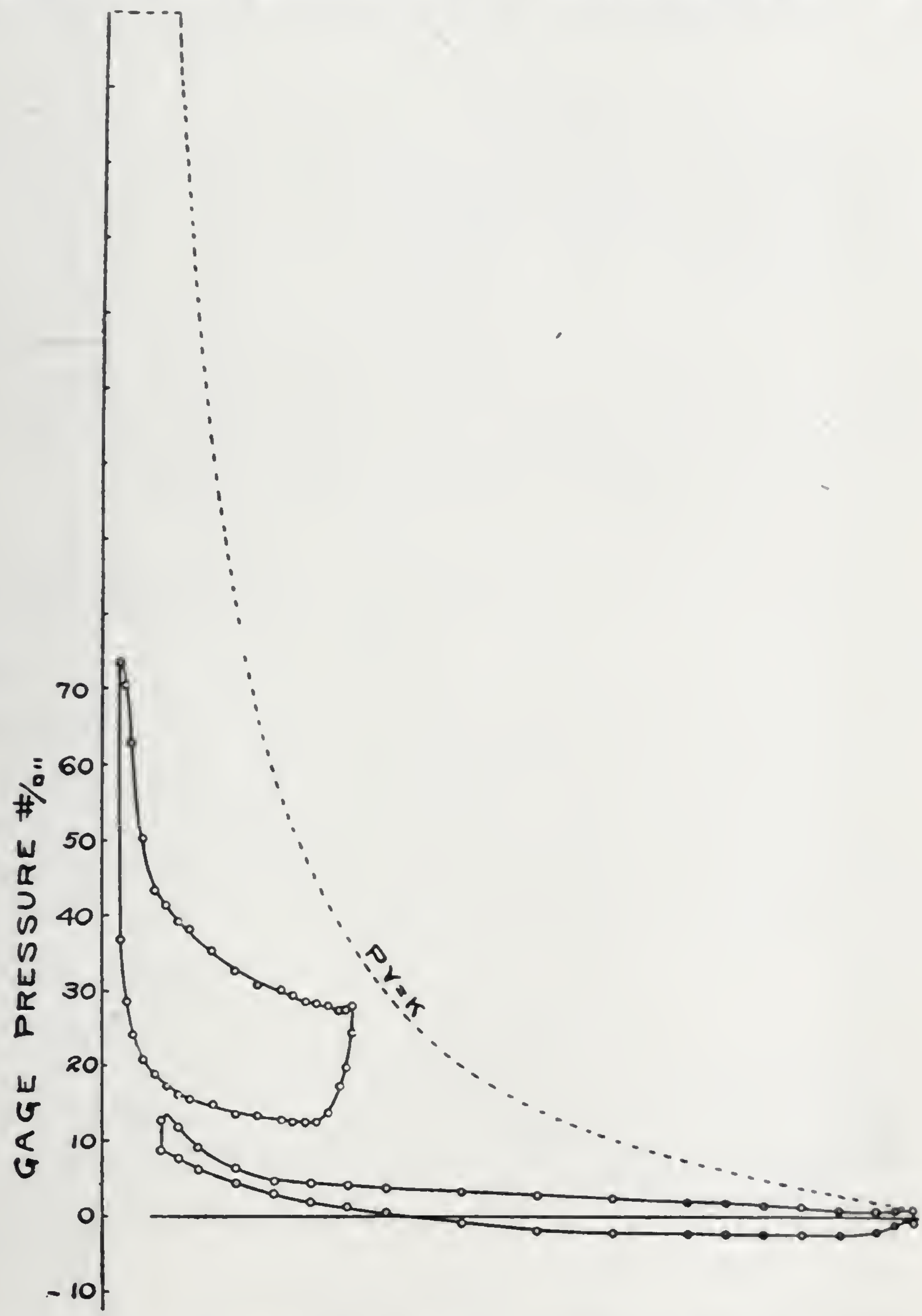


Fig. 56. Combined Indicator Card for Plugging Strokes, Brier Hill Steel Company's Engine.

portion of any individual card or stroke is omitted from the combined card.

The steam consumption is figured from this card in the same manner as was explained in the writer's discussion of Mr. Nibecker's paper.

The summary for the steam consumption is as follows:

	Sheet & Tube Engine	Brier Hill Engine
Dry steam, pounds,		
A—Just before release, h. p. cyl. (working)....	1060	960
B—Clearance volume of h. p. cyl. (plugging)..	28	12.5
C—Steam used in plugging h. p. cyl. (not charged)	437	316
Total dry steam.................	1088	972.5
Condensation, pounds,		
D—Condensation from A @ 25%............	267	240
E—Condensation from B @ 25%............	7	3
F—Condensation from C @ 25%............	109	29
Total condensation per ingot......	383	322
Total steam charged per ingot..............	1471	1294.5
Total weight of ingot, gross tons (2240 lbs.)....	2.56	2.81
Total steam charged, pounds per gross ton of steel rolled	575	462

The above sets of figures are not comparable, for one engine is condensing and its figure does not contain the steam for condenser auxiliaries and the other engine exhausts to a heater and its figure does not include credit for same.

Data were not taken during either test which will allow of precise correction, but allowing 20 percent as the saving of condensing over noncondensing engines, and charging 2 percent for condenser auxiliaries, we have:

	Sheet & Tube Engine	Brier Hill Engine
Steam for condenser auxiliaries (assumed 2%) pounds	12.5	none
Allowing net credit 20% for operating condensing, pounds	none	92
Total	587	370
Net steam saved, pounds per gross ton.........		217

Although this is a long step forward in the steam consumption of this type of engine, it can readily be seen from the combined cards that there is still a large field for engineers to decrease still more, the loss shown above the high pressure card and the loss shown between the high and low pressure cards, of the combined cards.

Prof. C. L. W. Trinks: The contribution offered by Mr. Coryell is very interesting, but it cannot pass without challenge, because it tends to discredit the work done by the engineering commission which tested the reversing engine at the Youngstown Sheet & Tube Co. It also tends to discredit the work of the builders of that engine by an artificial comparison of two engine tests.

Mr. Coryell tells the engineering commission consisting of engineers from (alphabetically arranged) Carnegie Institute of Technology, Carnegie Steel Company, Mesta Machine Company, and Youngstown Sheet & Tube Company, that their method of figuring steam consumption is wrong and then proceeds to figure a new steam consumption by a method of his own. The engineers in question met several times to discuss all points which might be doubtful. Furthermore, the steam consumption figures were checked by a heat balance on the condenser and by steam meter readings. When all three methods checked it was thought safe to publish the results, but Mr. Coryell says that we were wrong.

An analysis of Mr. Coryell's contribution seems necessary for the sake of correcting wrong impressions. Let us take first the method of figuring steam consumption. Mr. Coryell averages the ordinates of all of the positive cards and computes the steam consumption from the artificial card thus obtained. It is known that a steam engine is wasteful both at very short and a very long cutoff. Averaging brings both of these to a more economical cutoff. The method is therefore misleading.

Mr. Coryell compares the tests of two engines and gives the steam consumption per ton of steel. The comparison is such that it must impress the uninitiated with the fact that one engine is much more economical than the other.

In the test cited by Mr. Coryell (Brier Hill) the steel was

elongated seven fold as figured from the ratio of initial and final cross section. It is stated in the paper that initial and final lengths were measured. Now why were not these lengths used instead of areas? In tests which I have made, I regularly found the actual elongations, as measured from the lengths, to be less than the ideal elongations as determined from the area ratio. This is due to closing up of voids in the steel. It should be remembered that the Youngstown Sheet & Tube Co. test is based on actual elongations. If the steel at Brier Hill Steel Co. behaved the same as at Youngstown Sheet & Tube Co. it had only six and one-half elongations instead of seven. Now let us compare the two tests. For six and one-half elongations there are used per ton of steel at the Youngstown Sheet & Tube Co. 380 pounds of steam with saturated steam of 150 pounds per square inch pressure. According to Mr. Coryell, the Brier Hill plant uses 370 pounds, with superheated steam of 160 pounds per square inch pressure. It should be emphasized again that the Youngstown Sheet & Tube Co.'s tests were checked and rechecked and were compared with a heat balance of the condenser, and with readings of a steam meter. It is at least doubtful, whether equal care was used in the Brier Hill test.

After establishing the fact that the two plants (mill and engine) are at least equivalent with regard to steam consumption per ton of steel, we must go more deeply into the question: "What determines the steam consumption per ton of steel?" Of two duplicate engines one may easily use twenty percent more steam per ton of steel, because the steel is rolled faster or because the engine is handled with less skill. Besides, temperature of steel and inertia of revolving masses in the mill, coupling and pinions affect the steam consumption. The fact that the pyrometer readings in the Brier Hill Steel Co. test were rejected and that the excuse of cold steel was offered, looks somewhat suspicious. Returning to the speed of rolling, we must face the fact that fast rolling increases the inertia losses due to excess acceleration work and due to plugging. From personal observation at both plants, I know that rolling at the Youngstown Sheet & Tube Co. is faster than at the Brier Hill

Steel Co. Mr. Coryell gives in his report a time of 80 seconds for seven (or $6\frac{1}{2}$?) elongations, whereas at the Youngstown Sheet & Tube Co. 85 seconds were observed for 11 elongations. Besides, 31 of these 85 seconds were lost in manipulation, that is to say due to influences caused by the operator and the mill equipment, so that only 54 seconds remained for actual rolling.

If engines are to be compared as engines, or prime movers, we must give Rankine cycle efficiency, that is to say the percentage of that energy which could be converted into mechanical work by an ideal engine under given conditions of initial pressure, superheat and back pressure. The Rankine cycle efficiency of the Youngstown Sheet & Tube Co.'s engine is $36\frac{1}{2}$ percent. It would be interesting to have the Rankine cycle efficiency of the Brier Hill engine. In comparing these efficiencies, let it be remembered that it is easier to produce a high Rankine cycle efficiency non condensing, because the expansion line is steeper, allowing a closer approach to the back pressure line.

Two other points that determine the value of a reversing engine are uniform turning moment and ability to start and stop quickly without losses. The two conflict (see Mr. Kennedy's discussion). If we put sufficient masses into the rotating parts for an even turning moment, the engine will not start or stop quickly. If we reduce the masses to accomplish the latter purpose, the turning moment is uneven at short cutoff and the rolls wear due to slippage. Evidently the engine with smaller rotating parts will have the smaller acceleration losses and consequently the smaller steam consumption per ton of steel, but it only reduces one of the two evils, making the other one worse. The remedy lies in the three crank reversing engine.

Now to the devices that make the handling of the Brier Hill engine supposedly superior. Mr. Coryell attributes this alleged superiority to the low pressure throttle valves. Being responsible for the introduction of low pressure throttle valves in the United States, I know something about their advantages and disadvantages. They necessarily dissipate energy by double throttling and are consequently more or less a makeshift. (See paper by the writer on compound reversing engines read be-

fore the Society in 1905.)* An arrangement which cuts the steam off at the low pressure cylinder without throttling is more efficient than the low pressure throttle and is just as effective. The Youngstown Sheet & Tube Co.'s engine has such an arrangement.

Summing up I find that:

First: The steam consumption per ton of steel at the Youngstown Sheet & Tube Co.'s plant and at the Brier Hill Steel Co.'s plant is practically the same when referred to equal conditions of steam pressure, temperature and back pressure.

Second: Rolling at the Youngstown Sheet & Tube Co.'s plant is faster than at the Brier Hill Steel Co.'s plant, because the furnace capacity is greater.

Third: With equal steam consumption per ton of steel, that engine is more economical (as an engine) which rolls faster, because the same quantity of steam covers greater acceleration losses.

Mr. W. C. Coryell: In presenting a paper for publication, an engineer should make a sincere effort to discover and to correctly apply concrete truth so as to increase the sum total of human knowledge; or, he should accumulate existing information and so arrange it that the subject in hand is thereby clarified. His sole object should be to make it possible for others to do bigger and better things. He should not belittle or ignore a leading fact, nor magnify and exalt a minor detail. Lastly, when one meets error, he should recognize it; but, unless he corrects it or gives something better, he has done nothing. These principles have been followed by the writer.

Although the writer was a member of the party who made the Youngstown Sheet & Tube Company test, he was not aware of there being a Commission until so advised by the discussion of Prof. Trinks who modestly refrains from giving the personnel of the Commission, perhaps for the reason that two out of the four concerns mentioned were represented by himself. It may be assumed, therefore, that his was the guiding mind at the meetings and consequently, he deserves most of the credit.

*See paper on "Compound Reversing Engines" by Willibald Trinks, Proc. Engs. Soc. West. Pa., 1905, vol. 19, p. 235-254.

The writer, not being one of the Commission, worked alone and, in doing so, developed a method of his own.

The steam consumption per ingot has been obtained by the writer, both by the method of the Commission and by his own method. The former calculation agreed with that of the Commission within 4 percent while the latter calculation was 37 percent higher.

Now in non-reversing compound engines, the combined card usually shows the more steam in the low pressure cylinder, due to a re-evaporation, but in both of the reversing engine combined cards the more steam apears in the high pressure cylinder. The Commission measured the steam from the low pressure cards. The cause of the shortage in the low pressure cylinder is the heavy condensation in the high pressure cylinder and the receiver, not only during plugging but also during the interval when the engine is down between passes. The writer ran a test on the receiver and found a pressure drop during manipulation of the piece, when the engine was at rest, of two pounds every five seconds for a considerable drop in pressure. This loss in pressure checks well with the drop to be expected due to the radiation of the exposed surface. The low pressure throttle valves were closed and did not leak. Therefore, since the elements causing condensation are proceeding during plugging and during the rest period at reversal, the condensation factor must be applied throughout the rolling period. Usually the plugging steam should be neither charged nor credited, but this item must be determined by the individual card or the combined card. Therefore, if the Commission would have another meeting and adopt these additional items, the two methods will agree.

The writer has already expressed himself with regard to steam meters in steam mains subject to a wide range of velocities, and also on condenser tests. But since the two have been brought up again, it must be replied that the steam flow through the meter is from zero feet to several hundred feet and back to zero again in a period of a few seconds. In the particular condenser test, the hot well is small causing violent surging and counter currents; and the weir was rectangular, cut rather deep for its width out of two inch planking without champfering of the edges. Neither test was of any value as a check.

Prof. Trinks states that averaging a card with long cut off and one with short cut off tends to produce a card with a more economical cut off. If therein lies the cause of 37 percent difference between the two methods of figuring steam consumption, something more substantial should be done than simply to pass it by with the remark that it is misleading. As a matter of fact that point was looked into in the beginning. It was found that the error in this method of combining a long and a short cut off is less than one-half of one percent. But the actual series of cards are made up of long, short and intermediate cut offs and on that account the error is less than one-quarter of one percent.

A criticism has been offered to the comparison of the two engines on the basis of pounds of steam per ton of steel. There can be no objection to the unit since it has been used heretofore by nearly all writers upon the subject, including all the members of the Commission. Prof. Trinks has used this basis in connection with this very test. Of course, comparisons of engines must not be made on this basis when the mills are of widely different types, or when the number of passes are quite different, or the elongations are widely different. Now these mills are of the same type, have the same number of passes, and the elongations are not very different. The increased elongation at the Youngstown Sheet & Tube Company mill is simply due to a slightly larger elongation per pass than at Brier Hill. The average elongation per pass at the former plant was 14.4 percent while at the latter it was 12.1 percent. This is a disadvantage to the Sheet & Tube engine of 11.9 percent. Along with this, it might be well to recall another omission. The ingot at Brier Hill was the colder and its coefficient was, $C =$ 17 300, while at the Youngstown Sheet & Tube Plant it was $C = 13\,700$. This is a disadvantage to the Brier Hill engine of 12.6 percent. So the writer believes he was fair in omitting both items.

There is nothing in the argument that elongations instead of reductions should be used. Prof. Trinks mentioned the "closing of the voids." Two other items cause shrinkage, namely, scaling and cooling. All three items taken together are less than one percent, when each is a maximum.

The Rankine cycle efficiency also is of no importance. That is merely an expression showing the efficiency which a perfect engine would have when working under prescribed limits. The important point overlooked by Professor Trinks is, which of the engines comes nearest its ideal. There is no doubt but that the Sheet & Tube Company's engine is operated faster when one counts revolutions and is operated slower when one counts the number of passes, and the two are operated equally well with respect to speed of rolling when one considers reduction per pass and time.

The writer agrees with Mr. Kennedy and Prof. Trinks with regard to turning moments and the quick starting and stopping. It would be interesting in this connection to compare the weights of the reciprocating parts in order to see how much the "excessively heavy moving parts" of the Sheet & Tube Company's engine, as they are styled in the leading paper, are the cause of the excessive plugging.

Mr. Nibecker's estimate that plugging should not exceed 15 percent tallies very nicely with Brier Hill's 13.6 percent.

It should be recalled finally that the writer has held that the steam consumption figured by the combined card method is 37 percent higher than by the method of the Commission. The points made by Prof. Trinks show a total error of about one percent.

In conclusion, it must be recalled that the main points brought out by the writer are:

First: Condensation must be charged during the plugging and reversing periods as well as the working period.

Second: The combined card is a convenient method of determining steam consumption.

Third: The low pressure throttle valve is a steam saver due to five facts, brought out in the discussion.

Fourth: Machine spindles and cut gears save about 18 percent of the total work.

Mr. Karl Nibecker:* Referring to the test of the Brier Hill engine as reported by Mr. Coryell and the comparisons which he makes of the results of this test with the results ob-

*Authors closure.

tained from the Youngstown Sheet & Tube Company engine, I do not agree with several of his methods employed on this test, and also do not feel that the two tests are comparable in any way, the reasons for which I shall endeavor to show.

The indicator cards have all been traced, which seems to me to involve a tremendous amount of unnecessary labor and introduces a considerable inaccuracy. It is manifestly an exceedingly difficult proposition to accurately trace the curves produced by an indicator on a reversing mill engine, which is especially true in the case of the closed diagram cards. The closed diagram indicators used by Mr. Coryell were of very short stroke with the cards spaced very close together, thus greatly increasing the difficulty of tracing, as done by Mr. Coryell. In the case of the open diagram indicators, this tracing would be a much simpler proposition, although I feel it to be subject to a considerable error for actual determination.

From the set of cards, (which I had the privilege of seeing at the time of making the test) I am at a loss to know how tracings, such as Mr. Coryell shows, can be obtained. The cards as traced, are all of approximately the same length, which would be a very difficult thing to obtain using indicators of three different styles, as Mr. Coryell did. The cards as plotted, appear as though in tracing all cards were reduced to approximately the same scale in order to simplify calculations. This is certainly a difficult and dangerous procedure. In the case of the closed diagram, the two strokes, of course, should be of different lengths.

If the lengths as exhibited of the low pressure cards, taken with closed diagram indicators, are checked, it will be noted that the difference in length of the two strokes is practically negligible, which would clearly manifest the great difficulty in tracing the cards, due to their very close spacing. The average of the difference in length not being more than a sixty-fourth of an inch, as measured directly from the cards which Mr. Coryell shows. From these facts, it will be seen that it would be practically impossible to plot the cards and have them in any way accurate as a true representation of the operation of the engine.

Referring to the high pressure cards, Mr. Coryell states

that all high pressure cards were taken on open diagram indicators. I notice that the high pressure cards are not of absolutely uniform length, which would tend to show either that the indicators were not operating properly, or that the cards have been distorted in tracing, as the open diagram cards should all be of an equal length. These discrepancies in the lengths of cards must certainly represent a considerable error,—either in replotting or due to the instruments not working properly.

Mr. Coryell states that the engine and mill were running under normal conditions. He also speaks of their being "some" delay caused by the mill running on reheated steel. This delay was such that at no time was the mill being operated at maximum capacity, as a very small number of ingots only were rolled during the entire day. The operating conditions were such that on each ingot the engineer had ample time to operate the mill to the best possible advantage for consuming the least power in stopping the engine as the ingots were handled with a considerable interval between each two. This condition, I believe, accounts for the few number of strokes, as the work of rolling could be used for retarding the moving parts without impairing the speed of production.

In general, Mr. Coryell's method of calculating this test is similar to that used in calculating the test of the Youngstown Sheet & Tube Company, but the results are certainly not comparable, as one engine is run condensing and the other run noncondensing, the size of the ingots are not the same, and the Sheet & Tube engine was rolling with a much greater number of elongations.

Mr. Coryell states that about 10 deg. Fahr. of superheat was used. As superheat may effect the accuracy of the steam consumption, it would be well if he had given an accurate number of degrees of superheat as measured by the calorimeter. This however, it will be noticed, has not been done.

In describing the valve gear, the advantage of retaining the high receiver pressure for plugging, due to the closing of the valves, is mentioned. While it is advantageous to conserve this pressure for retarding the engine, I do not feel that any excess in pressure is conserved by this means over what would

be the case with an engine running at a high rate of production making reversals quickly and using this steam immediately following large power strokes.

It is unfortunate that Mr. Coryell has not shown any dead center markings, as they will definitely locate the points of reversal and eliminate any possibility of error.

As no record of seconds, or one of entering and leaving the rolls are indicated, it is also impossible to check the rolling time by this method. It would be exceedingly valuable if a proper record from the magnets on the indicators, or from the chronograph, were available, as it would then be possible to study and actually determine the action and effect of the valve gear and mechanism used in operating this engine to produce the exceptionally good results, as claimed by Mr. Coryell, from the indicator cards alone. We believe that these further records are quite indispensable in making such a test in order to have the results absolutely checked and of actual value.

It is unfortunate that Mr. Coryell has not plotted a curve of steam per ton per unit of elongation. If this curve is plotted for each pass, a very good check on the steam is made, as the curve should be smooth and the steam consumption can thus be traced for the whole operation.

In comparing the Brier Hill engine with The Sheet & Tube engine, Mr. Coryell has apparently lost sight of the fact that the Brier Hill engine was rolling with 7.07 elongations, while the other engine was rolling 10.75 elongations. The length of the finished piece at Brier Hill was approximately 40 feet, while the length of finished piece at the Sheet & Tube was 51 feet. It is thus seen that the Sheet & Tube engine used 2.25 revolutions per foot of finished length of piece for 10.75 elongations, while the Brier Hill engine used 2.36 revolutions per foot of length of finished piece for 7.07 elongations. This alone, would seem to be a decided indication of a much faster mill in the case of the Sheet & Tube engine, as the rolls used on both mills are of practically the same dimension,—the body of the roll being approximately the same.

Mr. Coryell speaks of the mill having rolled 50 ingots per hour. The Sheet & Tube engine has rolled 55 ingots per hour,

the ingots being larger than those handled at Brier Hill.

The total work expended per ingot will be seen to be 15 percent less in the case of the Brier Hill engine than in the case of the Sheet & Tube engine. The elongations for the Sheet & Tube ingot are 34.3 percent more than for the Brier Hill ingot. It is thus seen that 34 percent more elongations are produced with 15 percent more work, or the mill appears to be a more efficient one. Mr. Coryell does not calculate the number of cubic inches of displacement, as he is an advocate of the hyperbolic logarithm formula. The discussion of this question can be found in Vol. 29, No. 8, of the Proceedings of this Society. We, however, have displaced a much greater quantity of metal per foot of ingot rolled than has been displaced by the Brier Hill engine, as our ingot was $18\frac{1}{2} \times 20\frac{1}{2}$ average and rolled to $4\frac{7}{8} \times 7\frac{1}{2}$, while his ingot was 18×20 average and rolled to $7\frac{1}{16} \times 7\frac{1}{4}$, the amount of metal to be displaced in the former case being much more than in the latter.

It is interesting to note that the coefficient of the Brier Hill mill is 17 300 while the coefficient of the Sheet and Tube mill is 13 700. Mr. Coryell explains that this high coefficient is due to reheated ingots not being sufficiently hot at the center. In the early part of his paper he also speaks of the pyrometer readings being evidently in error, and, therefore, no temperatures are available.

Mr. Coryell does not feel that the Hallwach's meter as used by us is sufficiently accurate as he feels that the readings are proportionate to the square root of the mean height of the mercury column and not to the mean of the square root of the height. Mr. Coryell's assumption in this respect is wrong as applied to the meter which we use. The meter is so constructed that the height of the mercury in the manometer tube is not recorded on the chart, but the height of the ordinates on the chart are proportionate to the quantity of steam flowing. Therefore, the mean height of the chart represents the mean quantity of steam flowing and not the mean height as suggested by Mr. Coryell. The quantities which Mr. Coryell adds to the steam determined from the indicator cards for condensation, must be estimations which we grant are more or less scientific. I would

ask, however, how Mr. Coryell is to check these constants if a steam meter is not used? The difficulty of checking these by means of a condenser will readily be appreciated when the size of the engine under consideration is considered.

We have checked the coefficients as applying to our engine by means of a steam meter and find that they are quite correct. If Mr. Coryell feels that his coefficients are absolutely accurate, he has checked our meter; we however, feel that the meter is accurate and we have checked Mr. Coryell's coefficients for the Sheet and Tube engine, while we do not feel that we have any check for the Brier Hill coefficients, as no meter was used and it is highly probable that no two engines require the same diagram coefficients. We do not feel that condenser tests from a barometric or any type of jet condenser are reliable when applied to a reversing engine. The conditions change so rapidly that it is manifestly impossible to obtain sufficiently accurate temperature measurements. This is also true of water quantity measurements for the quantity of water flowing varies with each slight change of pressure in the condenser. This question has been mentioned in the leading paper; the check in that case as found did not correspond with the quantity of steam measured, but was only fairly accurate even when all possible refinements of measurement had been made.

I am at a loss to know why steam cannot be discharged back into the steam chest, as the pressure in this chest is controlled by the throttle valve and not by the boiler pressure, which Mr. Coryell assumes to be the case. If the condensation of steam is charged on the working strokes only, this would appear to be all that is necessary, for in the plugging or compression strokes mentioned by Mr. Coryell the steam is operating in a closed cycle of compression and re-expansion, so that excluding radiation, which will be small, the condensation and reevaporation should be equal. We, therefore, do not feel that the condensation on plugging strokes should be charged.

As regards the 20 percent credit to the Brier Hill engine, it must be remembered that this is only a justifiable credit in case all the heat from the engine exhaust can be used for boiler feed water. If this steam can be successfully used in heating

the feed water, the credit is a proper one. In this plant a large amount of steam is wasted to the atmosphere, so that it is rather a difficult question to determine how much credit is justly due for this feed water heat.

By making a direct comparison of the Sheet and Tube engine at 7.07 elongations with the Brier Hill engine, charging the Youngstown engine for auxiliary steam, it is found that 6.2 lb. per ton less steam is consumed in the Sheet and Tube engine than in the Brier Hill engine. This is making a direct comparison on elongations alone without regard to displacement which is greater in the former than is the case in the latter engine. The value of steam consumption as found for the Sheet and Tube engine by means of a large number of steam meter tests is clearly shown in our Fig. 29.

To sum up the comparison of these engines, I would submit tabulation as follows, giving the figures as presented by Mr. Coryell and also the Sheet and Tube figures, corrected, as described above, and the Sheet and Tube figures for 7.07 elongations determined from curves plotted.

ENGINE	Y. S. & T. Co.	Y. S. & T. Co.	Brier Hill Steel Co.
Size of Ingot (Average)	18½ × 20½	18½ × 20½	18 × 20
No. of elongations	10.75	7.07	7.07
Total No. of strokes per ingot	115		94
No. of plugging strokes per ingot	45.5		30.6
Length of ingot, Ft.	4.75	4.75	5.63
Length of finished piece, Ft.	51	33.6	40
Strokes per ft. finished length	2.25		2.36
Total work expended, Ft. lb.	110 409 000	72 700 000	93 000 000
Work used in rolling, Ft. lb.	58 615 000	38 600 000	68 335 000
Time of rolling ingot	85		80
Ingots per hr.	55		50
Coefficient $C = \dfrac{Work\ (in\ ft.\ lb.)}{A\ L\ Hyp.\ Log\ (A \div a)}$	13 700	10 940	17 300
Total lb. steam per ingot	1 471	1 126	1 272.5
Weight of ingot (tons)	2.56	2.56	2.81
Pounds steam per gross ton steel	533	438	453
Pounds steam for auxiliaries	10.6	8.8	
Total lb. steam per ton steel	543.6	446.8	453

As mentioned by Mr. Coryell, a sincere effort should be made to report engineering facts in such a way as to increase the total information available upon a given subject.

In the leading paper, as well as discussions thereof, and the replies to these discussions, I believe, a sincere effort has been

made to report all facts and details in such a way that the engineering profession at large may be benefited. The discussions and the replies to them have all been given with extreme care and forethought, so that any one interested in the subject may analyze the data and form satisfactory conclusions of the facts as discussed.

As mentioned by Prof. Trinks, The Youngstown Sheet & Tube Company engine was tested with extreme care. The methods used, both in testing and calculating the results, were carefully discussed and the advisibility of their use conscientiously determined before they were adopted. The engineers concerned in this test, therefore, have certainly used their best efforts to produce reliable data of value to the profession.

It is most unfortunate that Prof. Trinks and Mr. Coryell, each of whom represent engine builders, and can, therefore, hardly be clsssed as impartial judges upon the subject, should have entered into a controversy concerning such minor details.

The results of the tests as given are presented simply at their face value, and it has never been the intention of the author to advocate any special scheme. It has been his object solely to present the methods which he has used and the results which he has obtained in the hope that they may be of some slight assistance to further investigators along this line. In the replies of discussions presented, the author has endeavored to present in a conscientious and scientific manner his views and the results of his experiments as applying to the questions brought out by the several gentlemen in their discussions of his paper.

The writer feels, that in view of the amount of discussion and questions which have been raised concerning the test reported in the leading paper, the necessity for a suitable commission to settle such points and definitely determine the proper methods is further emphasized. If it is within the power of this Society, we feel that the suggestion made by one of the members is a most admirable one, and that such a commission could doubtless avoid controversies, such as have arisen at this time, and thereby obtain data which would be comparable in every way and of greater value to future investigators.

RAILWAY CLASSIFICATION YARD LIGHTING

By D. P. Morrison*

Among the many problems peculiar to railroad operation, the process of sorting cars and their consolidation into trains, as carried on in what are termed classification yards, is a problem of the first magnitude of importance and interest.

The present practice is to perform this work in what are known as gravity or hump yards, and for the sake of a full understanding of the problem which is the subject of this paper, a brief description of such a yard and its operation will be profitable. Typical modern yards are shown in Figs 1 and 2.

The essential elements are: First, a lead, of sufficient length, to accommodate the longest train, approaching. Second, the Hump or summit, which is so arranged as to height and grade as to give the "cut" consisting of one or more cars, usually not more than three, the proper acceleration to cause it to clear the train and to carry it to its destination down (third) the ladder and into (fourth) the bodytracks upon which the train of which it is to be a part is being assembled.

The distance from the summit to the end of the ladder track may be from 800 to 1500 feet, according to the number of bodytracks into which it leads. The grade varies from 2.0 to 0.1 percent, some cases may be 4.0 percent, according to circumstances, and is usually sufficient to give the cut a maximum speed of about four miles per hour. The end of the ladder and the branches being on a grade of about 0.1 percent, or just sufficient to keep the cut in motion.

The process of operation is as follows: The train to be sorted is pushed up the lead by a locomotive at its far end, and when the car to be handled is just surmounting the summit it is cut from the train, and, quickly gathering headway on the

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comparatively steep portion of the hump, runs away from the train, thus making proper spacing between adjacent cuts. Before leaving the summit, each cut is manned by a rider who stands at the brake and whose duty it is to ride the car until it has reached its destination on a bodytrack, controlling its speed by means of the handbrake, so that it approaches the adjacent car with only sufficient speed to properly couple.

From the views shown of typical yards it will be seen that the physical extent may be very considerable, amounting to several thousand feet in length and 150 to 500 feet in breadth.

It will be seen also that the engineers have not been guilty of wasting much space which could profitably be used by the illuminating engineer, and it is this lack of space for lamp location which presents the most formidable phase of the entire problem. As the night work in such a yard is as important as the daylight work, it is evident that a satisfactory system of artificial illumination is most desirable.

The problem can be briefly stated as follows:

First: Such illumination of hump slope and ladder tracks as will be sufficient to render cars thereon visible at summit and in case of yards in which switches are operated mechanically to enable the towerman to have clear vision of the ladder and switches.

Second: To uniformly illuminate all portions of the body of the yard so that a rider, coming off the hump, will be able to see any car on the track ahead of him at a sufficient distance to properly reduce its speed before striking it.

Third: The light must strike cars and tracks at such angles and from such directions as will obviate, to the fullest extent, the formation of dark shadows which would prevent sight of cars ahead by the rider.

Fourth: The light must be so directed as to avoid, as completely as possible, any reduction of the rider's eye efficiency on account of glare.

In the above enumeration no mention has been made of intensity of illumination, as practice indicates that a very low intensity, if fairly uniform and without shadows, is entirely satisfactory; in fact low intensity does not constitute failure and a fair measure of allowable minimum intensity can be ar-

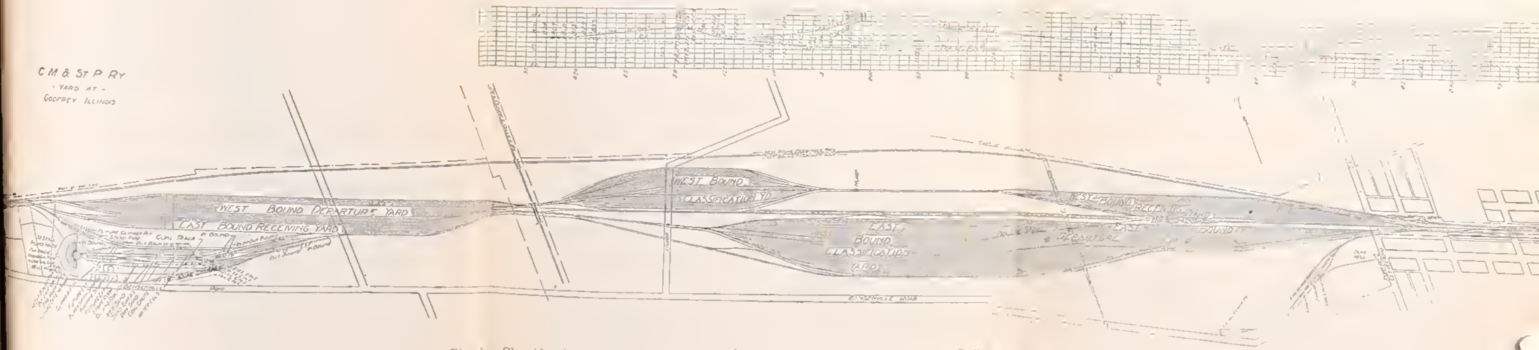

Fig. 1. Classification Yard at Godfrey, Illinois. Chicago, Milwaukee & St. Paul Railway

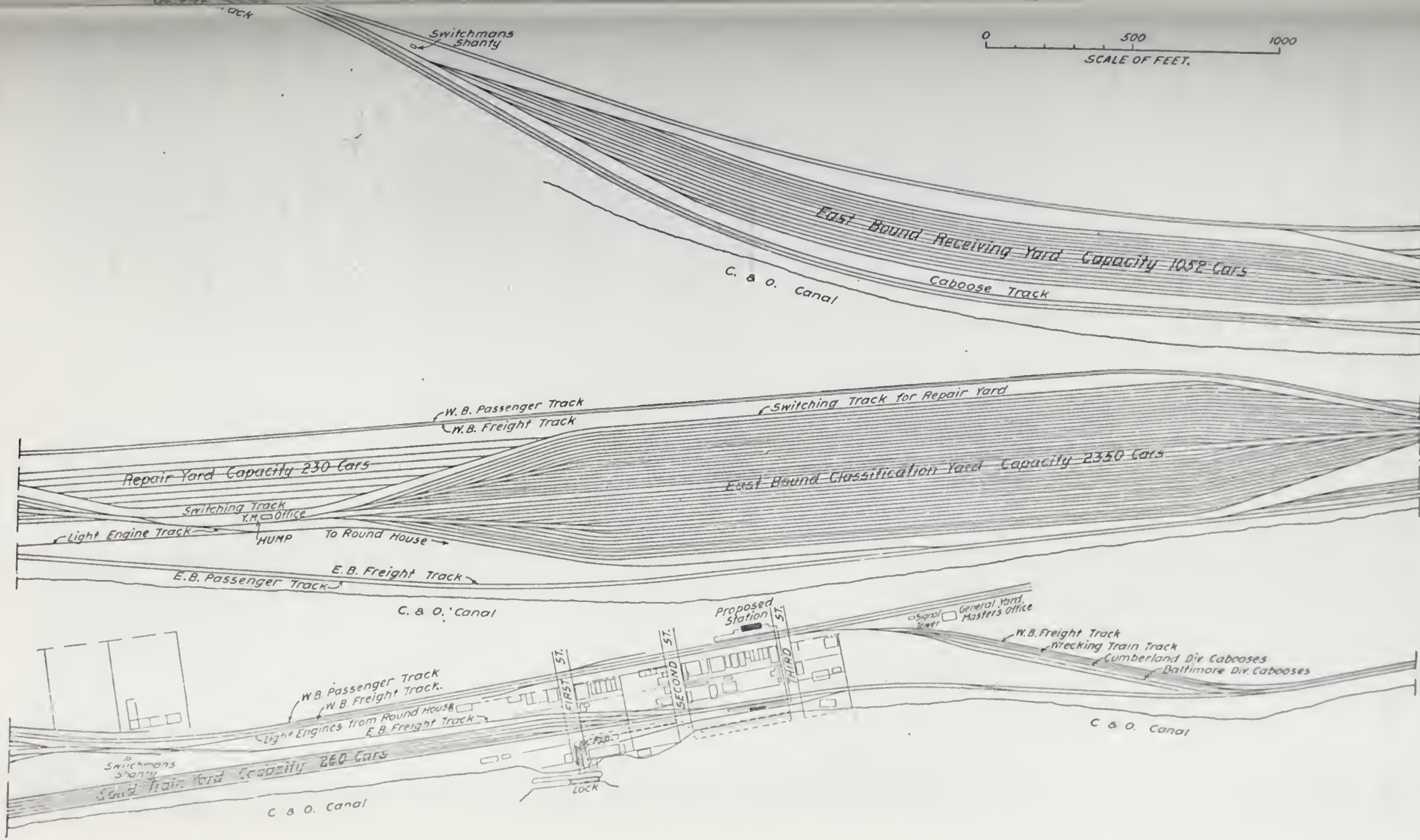

Fig. 2. East Bound Yard System at Brunswick, Maryland. Baltimore & Ohio Railroad.

rived at when it is known that good moonlight permits satisfactory operation.

The conditions of present practice, as has been recognized for some time, leaves much to be desired; so much so, that some companies have refrained from attempting the lighting of these yards, believing that a yard poorly lighted is more dangerous than a dark yard. In fact, I have, myself, been told by riders that they preferred to work in a dark yard than in some yards, the lighting installation in which must have cost many thousand dollars. It may safely be said, therefore, that the state of the art, as regards railroad yards, is no further advanced than it is in connection with street lighting which is as yet, with comparatively few exceptions, lacking in all the features of good engineering. A good understanding of the short comings of present installations will clearly suggest itself to any one who has driven a carriage in almost any of our suburban streets or country highways, under the usual condition of artificial lighting.

As being the only illuminant of high candle power which was available until within a very few years, the ordinary arc lamp was naturally selected for such installations. This has, in many cases, been replaced by improved types, but with similar spacing and mounting. In some yards in which the enclosed arc was originally placed may now be found the magnetite or other metal flame lamp placed on the same poles and at practically the same height as the lower candle power lamp, a procedure which must aggravate an already bad condition on account of the greater glare resulting. In at least one yard an attempt has been made to accomplish the desired result by means of a powerful search light installed at, or near, the summit and directing its rays down into the yard. It is no secret among railroad men that the results from this installation, while very good in certain respects, are nevertheless so unsatisfactory as to have prevented its duplication in any other yard. The point of failure in this scheme is the excessive glare, especially while the men are returning to the summit, on account of which their eye efficiency is seriously impaired. Failure would also result in curved yards, on account of shadows.

On account of the unsatisfactory results from installations

already made, it is not surprising that no attempt toward lighting has been made in connection with many otherwise modern yards. In the case of the P. & L. E. Railroad, none of its classification yards had been lighted prior to this year. For some time, however, it had been the feeling of many of its operating men that improvement of conditions should be made and a study of the problem was instituted. With the requirements as before stated as a basis, and with the plan of the yard, Fig. 3, (the Westbound Classification at McKees Rocks) for

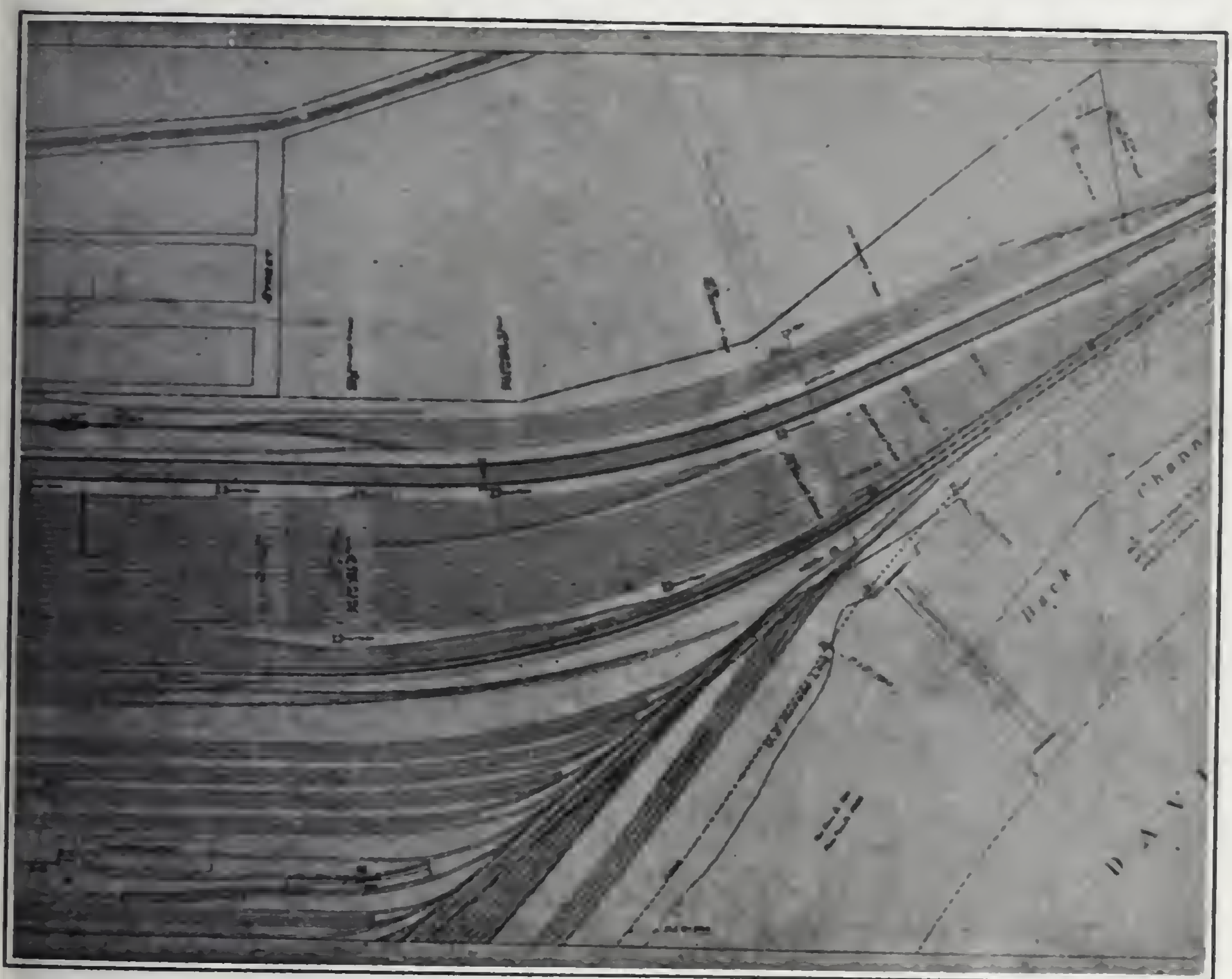

Fig. 3. West Bound Classification Yard at McKees Rocks, Pa.
Pittsburgh & Lake Erie Railroad.

study, it was seen that with the track spacing of thirteen feet, which will be found in most similar yards, the support design must be limited to suspension wires spanning the yard, or to poles placed on the outskirts of the yard. Two tentative plans therefore were worked out, the latter of which was finally adopted and is the main subject of this paper. The first, briefly described for comparison, involved the use of 150 watt Tungsten lamps in enamel steel reflectors spaced 60 ft. apart across the yard, and 150 ft. apart in the longitudinal direction, the

total power required being 10 k.w. These lamps were to be enclosed in 45 deg. angle reflectors, which directed the light to the ground, and in the direction of car movement. They were to be mounted at a uniform height of 37½ ft. above top of rail. Means for suspension consisted in steel catenary cables ⅝ in. diameter, attached to heavy steel or concrete poles, 45 ft. in height, on each side of the yard. The design of course included proper means of support of lamps and conductors to the catenary and means for inspection, renewal and repair by trolley sling traveling on the catenary. The results, obtainable by this

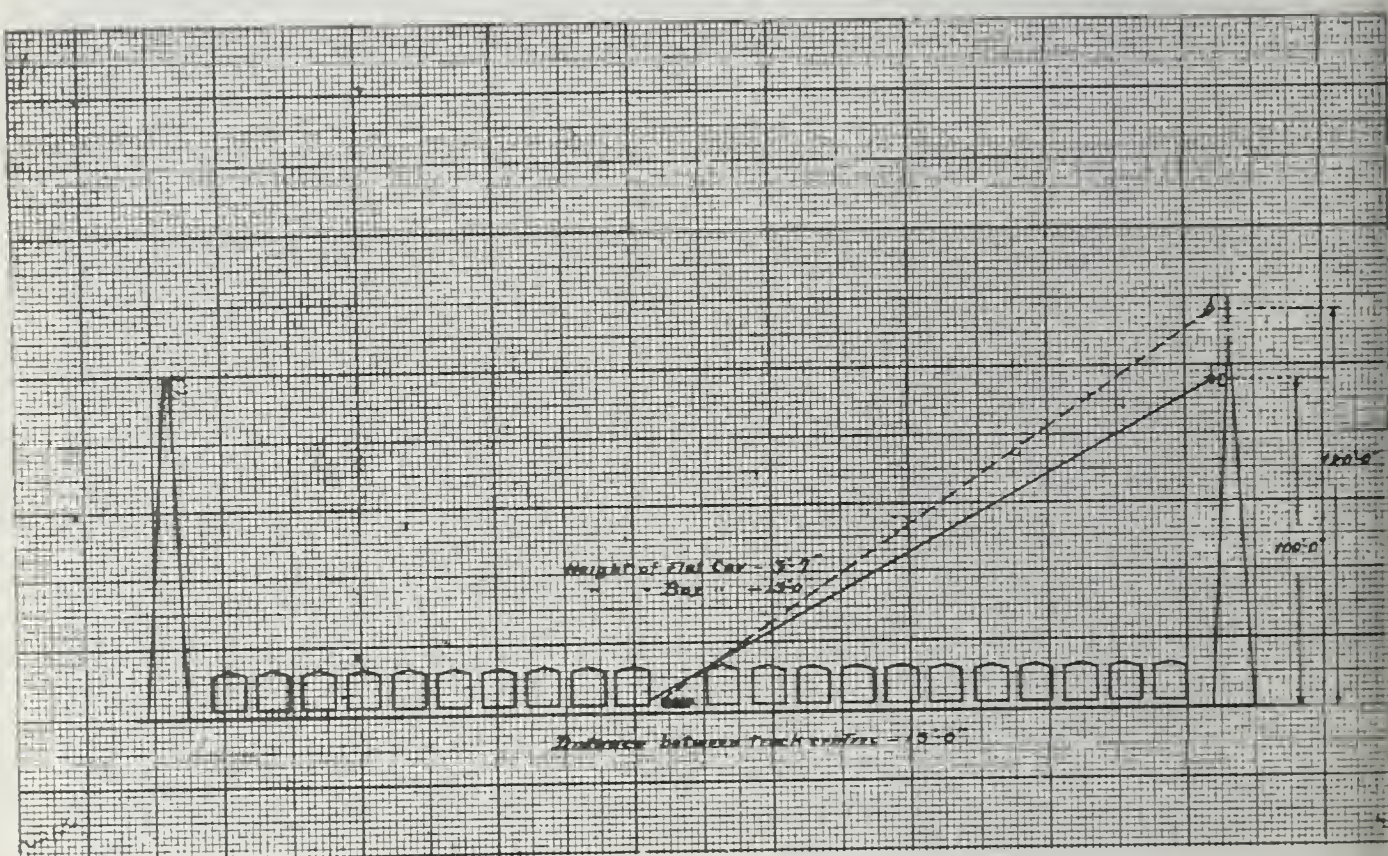

Fig. 4. Angle Diagram showing Determination of Height of Towers.

method, probably could not be excelled from an illuminating standpoint, but the plan was given up on account of high initial cost, heavy current consumptions and very uncertain maintenance and repair costs. The second plan, which was based on the use of high mounted lights, takes us back to the ancient days of street lighting and was the natural outcome, and the final details followed from a study of the angles involved, as shown in Fig. 4. An examination of this diagram indicated that with a yard 270 ft. in width, accommodating twenty-two tracks on thirteen foot centers, a unit would have to be mounted at a height of 120 feet to begin to be effective under the worst condition of spotting, which was assumed to be as follows:

A flat car 42 in. above top of rail in the center of yard with 14 foot box cars on each side between it and the nearest lamps. From the diagram it will be observed that a lamp so placed will light but a portion of the car, but on the other hand it does not take into account any possible addition to the direct light by reflection from other objects, and experience has shown that, with such condition, no car can be entirely in shadow. On

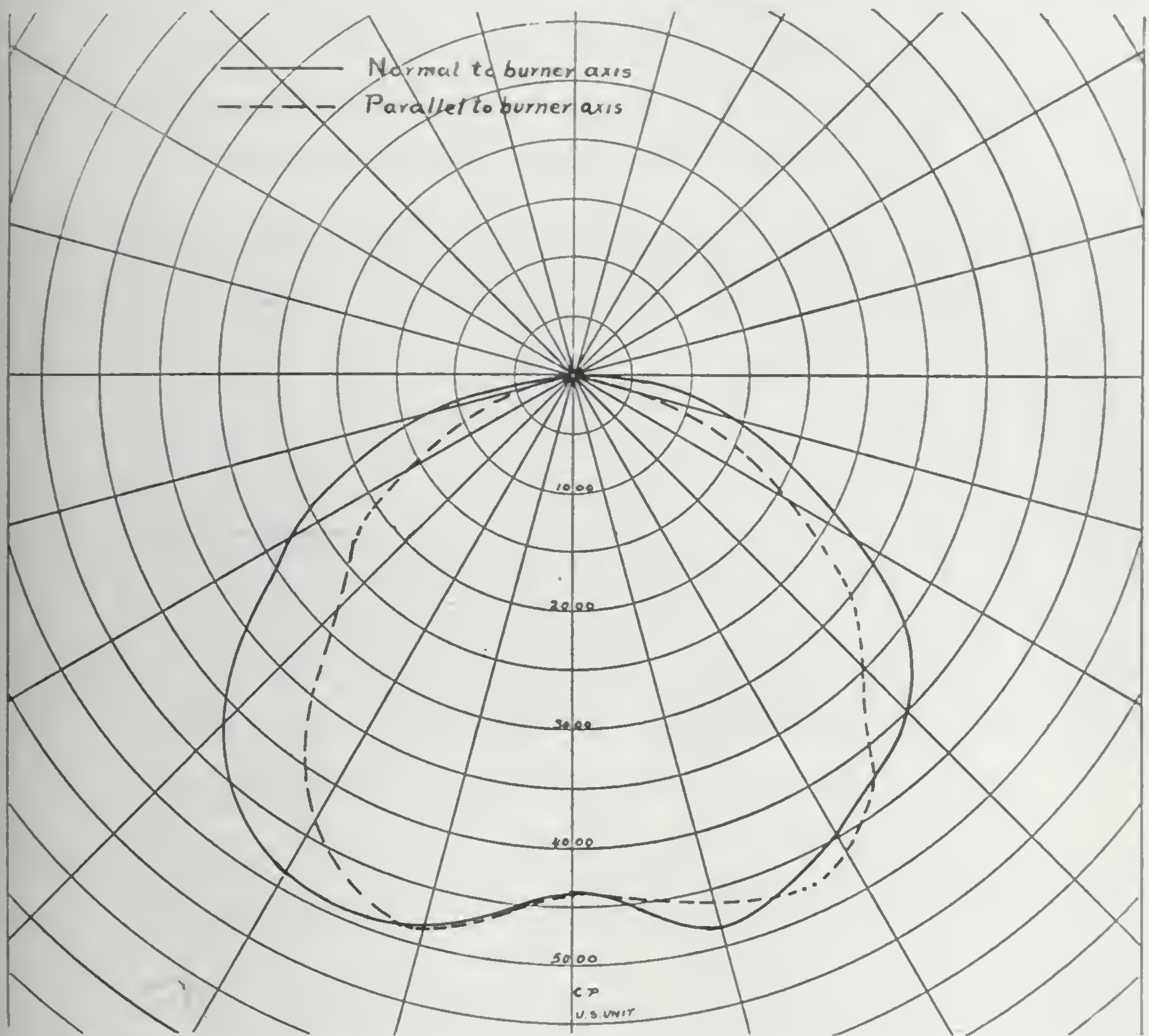

Fig. 5. Light distribution curves from quartz tube mercury arc lamp.

account of the extra height and cost involved, it was decided to limit the mounting height to 100 feet, which gives the result shown in diagram in solid line. The condition resulting is further improved by the light from units at the head of the yard which tends to strike the car end on account of the shape and curvature of the yard.

With a mounting design as above, the question of a suitable illuminant was of next importance. At the time of completion

of design, choice was limited to two or three units, namely, the flaming arc lamp, the quartz tube mercury arc, with a possible alternative of clusters of incandescent lamps or medium candle power arcs. The advent of the nitrogen filled incandescant lamps offers another alternative at the present time. On account of various factors, which need not be enlarged upon, choice was made of the quartz tube lamp, one being installed on each of eight towers. The curve of distribution of this lamp (Fig. 5) with ordinary downward reflector, indicates a maximum intensity at foot of pole of 0. 4 foot candle with a minimum 0.015 foot candle from each of at least two lamps, and an average over

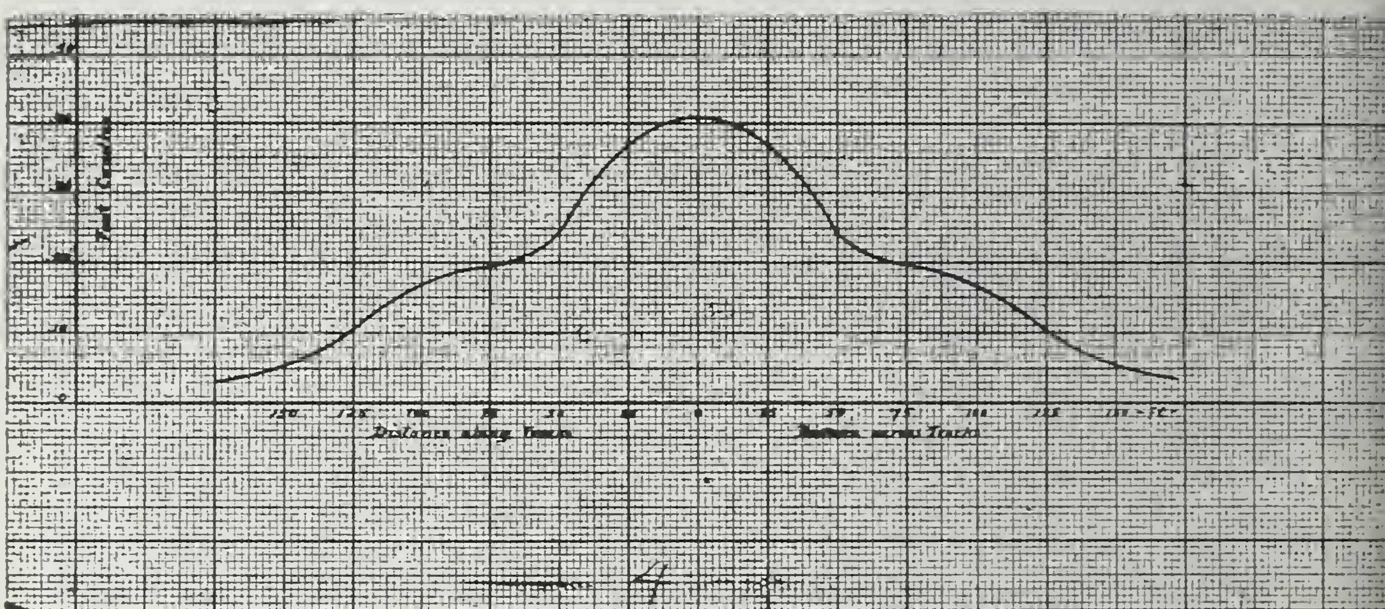

Fig. 6. Illumination on plane 95 feet below lamp.

the entire yard of 0.165. It is evident that from the standpoint of uniformity, this leaves much to be desired, (see Fig. 6), but tests indicated that the minimum value was sufficient for satisfactory work and the distances were so great that unequal intensities would not be objectionable, in fact hardly noticeable, and therefore no attempt was made to develop a reflector for this particular unit which would give the same flexibility of light control obtainable with incandescent lamps. These lamps, as hung, consume 3½ amperes at 225 volts, or approximately 800 watts each, totaling 6650 watts for the entire yard, including one 250 watt Mazda lamp placed near the top of the knuckle. This is equivalent to 75 square feet per watt (0.133 watt per square foot).

The towers involved no particularly new problems, the de-

sign being very similar to towers of equal height, commonly used in high tension transmission service. Certain features were added, however, out of deference to "Safety First", including a ladder from the ground up and terminating in a small platform at the top, surrounded by a railing 3½ feet high. This platform is entered from beneath through a hinged door, which, when lowered, forms the floor. It is protected on all sides by an angle iron with one side vertical which forms a foothold for the operator so that he can work with full protection when hanging or adjusting the lamp. The lamps were suspended from cut out hangers to further protect against frequent trips to the top.

The towers are made of structural steel angles and bars and are figured for wind stresses only. They are made of a tapering square section 12 ft. at the base and one foot at the top on each side, see Fig. 7. They have been designed using a double cancellation system of bracing on each side.

The sections of steel work are possibly heavier than necessary but it was thought best to use ample steel sections, especially in view of the fact that a railroad yard is a place where the steel work must necessarily be subject to rapid corrosion.

These towers are made up in three sections; the lower section being shipped out entirely knock-down from the shop; the middle section was shipped with two sides riveted up complete, the bracing and the other two sides shipped loose; the top sections were shipped completely fabricated from the shop. Each corner of the tower is anchored to the foundation with two 1¼ in. bolts, each foundation requiring about 5 cu. yds. of concrete. The towers were shipped to the yards in the condition mentioned above and assembled complete on the ground each on its side between the railroad tracks at foundation sites.

There are three horizontal sets of diagonal bracing at three intermediate points of the tower. This bracing was placed to hold the tower rigidly square and also to assist in the erection. It was found that they were quite stiff and could be handled by being raised from one point without any danger of bending. With a little additional wood bracing and wood protection beneath the wire cable they were picked up by a locomotive crane with 70 ft. boom at a point about 60 ft. from the base. As the

towers were lying parallel with the railroad track, the locomotive crane was run to a position where the boom could be set nearly straight up and the tower raised with the boom in a fixed position and the crane moved on the track as the tower was brought

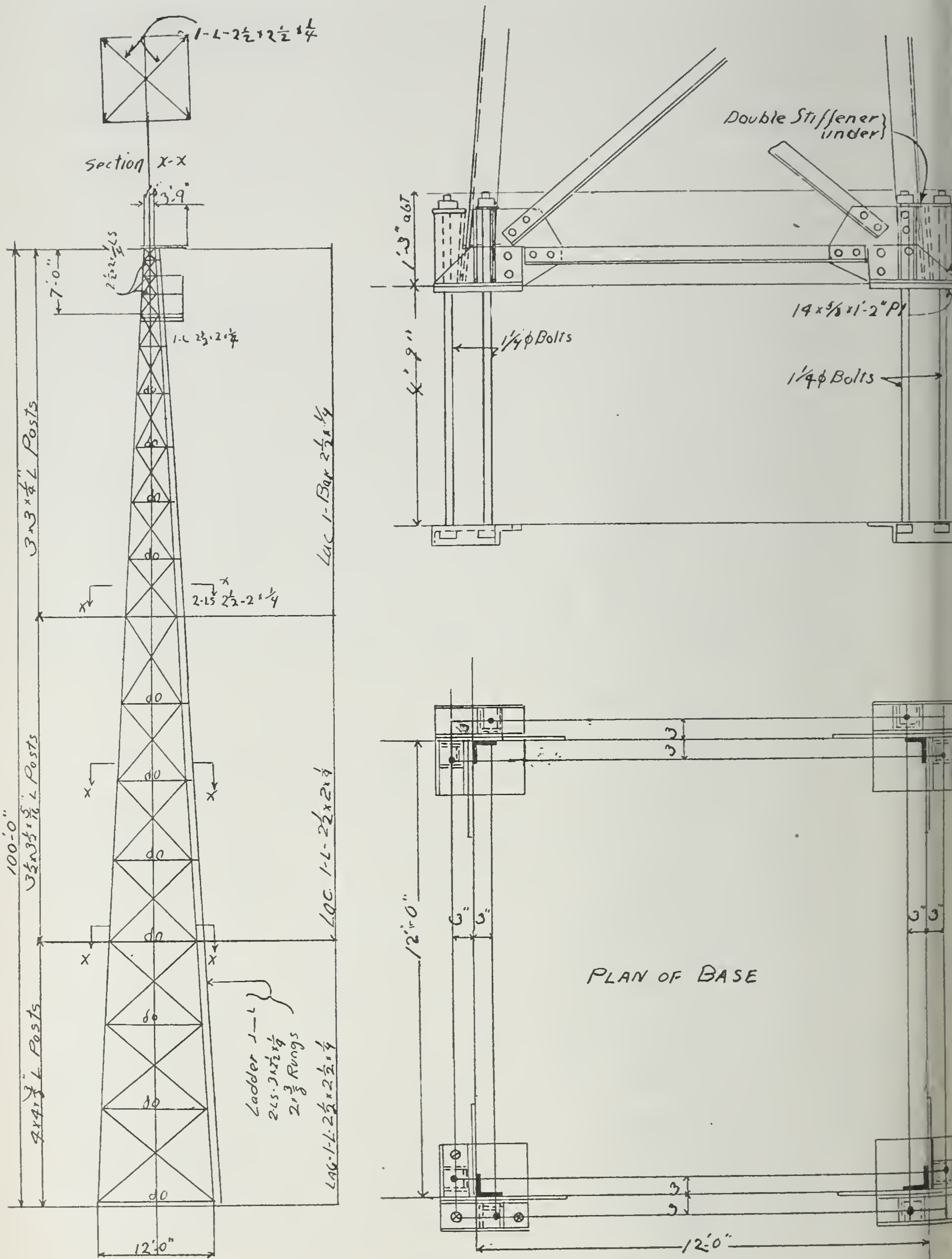

Fig. 7. General plan of towers.

in an upright position. Each tower with its ladder, platform and brackets complete weighs approximately 13,100 pounds.

While the costs of such an installation were necessarily large and, even though it did exceed the estimate, they were not excessive, and I believe are less than the same results can be obtained for in any other manner. If for this yard had been used a system such as is in use on one well known road, there would have been required at least fifty flaming arcs on 50 ft. poles, which would probably have cost not less than six thousand dollars, erected. The current consumption would have been 25 k.w. instead of 6½, and the attendance and maintenance would be correspondingly greater. It is certain that any catenary construction would have amounted to more in first and operating costs. The actual costs for the entire system, including local distributing circuits, but not including mains from power house which were already available were as follows:

Lamps, Distributing Poles, Wire & Electric Labor	$1256.00
Foundations, Towers, Engineering & Incidentals	6429.00
	$7685.00
Number of Units	8
Unit Cost	$854.00

Fig. 8 shows view of the McKees Rocks yard and Fig. 9 a view of the same yard at night.

In discussing results, it must be borne in mind that the experience of the operators, as far as their work on the P. & L. E. R. R. was concerned, had been entirely in dark yards. Their relief at any improvement in that condition could not help but reflect credit on the change. As an indication, however, that their attitude was not originally biased in favor of the system, it may be of interest to note the remark of one rider when informed that the service was to be tried out on a certain night, "Well, I guess I will come down and see you fellows make fools of yourselves". From this remark it can be understood that any criticism which would occur to the operators would not be suppressed for fear of hurting the feelings of the engineering force. A careful watch of results has been kept by the operating officials in charge of the yard, and individual reports have been made by the entire night force of riders. Their

reports have not been without some criticism, but an idea of the success can be had from the following report:

"Prior to this installation, trouble was experienced in keeping men on the knuckle, but at the present time the jobs are considered among the best in the yard. This crew is composed of twelve men and at present practically all of the positions are filled with old and experienced brakemen. The lights as they are located throw no shadows and a greater portion of the time the trainmen work without lanterns. There is a peculiar feature

Fig. 8. View of McKees Rocks yard by day light.

about this light and that is, that during the fog the rays appear to penetrate and show a car very prominently. The lights have been recommended by every trainman that has ever worked under them."

It has been interesting to note the ideas of the men as expressed in personal conversation, and to know that those who have worked in other lighted yards are satisfied that a better working condition is obtained under this system than under any with which they are familiar. A record of damage to property and personal injury shows a natural improvement. How this

compares with other yards is a matter which I hope may be enlarged on in the discussion.

An indication of the benefit from this standpoint is obtained from the following extract of a report issued recently.

"As an illustration of the benefits derived, during the month of April, 1914, we had nine accidents, damaging equipment to $557.00. Although the lights were in use but a short time in May, the accidents showed a decrease as to the number

Fig. 9. View of McKees Rocks yard by night, artificial light.

and damage. For the month of June we had six accidents and our equipment damaged to the extent of $59.70".

July 15. Car defective, broken coupler.
July 25. Sill gave way when car was coupled.
August 5. Crippled car broke down. P. M.
August 19. Brake ineffective. P. M.

The number of cars sent over the summit in September was the largest on our records.

In closing, a word should be spoken regarding the matter of glare which in all previous attempts at yard lighting has

proven the feature least satisfactorily solved. I believe that one of the chief causes of the success of this installation has been, the practically complete absence of annoying glare, which quite easily may be worse than darkness. The absence in this case is due chiefly to the great height of the lamps, so that no rays enter the eye below the critical angle, 66 deg., at a point nearer than 225 feet, as well as to the nature of the illuminant itself. It was suggested by certain gentlemen who were making an inspection of the system that it evidenced a good deal of courage to make such an installation, with lamps at such a great height. Whatever courage may have been exercised was displayed by the management which consented to the expenditure, as no new ideas are claimed for the design, but simply the application of principles and practices long since proven.

It is to be hoped that this description of what one company has attempted may bring about a consideration of the problem among the railroads and engineers sufficiently wide to result in a complete solution of this troublesome problem.

In closing I wish to acknowledge the assistance of the following gentlemen in the preparation of this paper: Mr. J. A. McEwen of the Pittsburgh Bridge and Iron Co., Mr. J. L. Minick of the Pennsylvania Railroad, Mr. Harold Kirschberg and the Cooper Hewitt Electric Company.

DISCUSSION

Mr. A. Stucki*: Judging from the picture, there is considerable light lost in an upward direction. Can this not be prevented by proper screens? Does not a great deal of light become ineffective on account of the high position of the lamps? I remember some years ago this very trouble in one of the parks was overcome by lowering the lamps.

Mr. Morrison spoke about the difficulty of placing the towers. Since the posts have to be spread for stiffness, has the question of straddling the tracks ever been considered?

The Author: In regard to so much of the light apparently going up that is due more to the picture than the direction of the rays. The tube has a rather sharp reflector which

*Consulting Engineer, Oliver Building, Pittsburgh.

throws the light downward. It is in the shape of a *V* and the skirts come down a little below the center of the tube, which practically throws the light all downward.

In regard to straddling the tracks: The towers are not wide enough at the base to straddle the tracks and there is not enough space between the tracks to place the legs which would have to be between the tracks as there is barely clearance between cars now.

MR. HENRY S. PRICHARD: Are the towers galvanized?

THE AUTHOR: No, sir.

MR. SAMUEL E. DUFF‡: I would like to ask something about the cost of this installation and also the continuous expense.

THE AUTHOR: The total cost was about $7700 for eight units, $854 per tower. The operating cost I have estimated as follows: During the last four months they have been in service since the latter part of May. Covering about four whole months we have a total of about $110, operating cost, which includes about $75 for current. And there were inspection, cleaning and some repairs which is included. Of course, we have not had very heavy repairs on the lamps and no repairs on the towers. I think you can count on repairs being small for many years.

I have some figures on lamp service so far and I expect to get 4 000 hours per lamp. The representatives of the lamp company are here and they can probably state what they are actually getting from lamps in similar situations.

MR. SAMUEL E. DUFF: What I wanted to say may not bear directly on this subject, but I sight back about 25 years in my own life to the time when I laid out and constructed a railroad yard under totally different conditions. What strikes me is the difference in construction and operation of that yard compared with yards today. That yard was built with all stub switches, about twenty parallel tracks, 13 ft. centers and tracks 1500 ft. long. For about six months after it was built, there were no switch lights in it. The work done at night in

‡Consulting Engineer, Empire Building, Pittsburgh.

that yard was probably one-twentieth as much work as could be done today in a yard properly equipped and lighted. What I was getting at was the cost of producing so much better conditions for operation. The investment in this McKees Rocks yard is something like $8 000, about $500 a year, roughly; current repairs, etc. about $50 a month of $600, or about $1000 a year and $1000 a year is only the wages of one man. I am very much struck with the wonderful advance.

I want to compliment Mr. Morrison on the photographs of the yard at night. It is a very fine piece of work and one which explains the effect of the illumination very clearly.

Mr. W. C. Copley†: There is one question I would like to ask regarding the yard to which the speaker referred as having tried out the search light and found it unsatisfactory, and which was not experimented with in any other yard.

The Author: I cannot give the name of the yard. It was described to me by some of the men on the Pennsylvania Railroad and I understood that the installation had never been duplicated.

Mr. W. C. Copley: We had, I think, the first search light ever installed, in the Altoona Yard. It has been duplicated in other yards and a duplicate set installed in the same yard. The lamp was found so satisfactory that it increased the efficiency of the yard about 20 percent, to almost the daylight efficiency.

At the start the men objected to the glare of the light, but this was due to the novelty of the lamp which induced them to look at it.

The first lens did not diffuse the light enough to cover the entire yard, which has about 30 tracks. We procured an additional lens which covered the entire 30 tracks, and the men became accustomed to it. After it was in operation about three months we ran out of carbons and the lamp was out of service a couple of nights and the men threatened to quit if they did not get the lamp back, or something as good to show them where they were going.

The first cost of the lamp is $300 and the additional special

†Freight Train Master, Middle Division, P. R. R., in charge of Altoona Yards.

lens cost $45, making the total cost of the lamp $345. The installation of the dynamos and other costs of installation was $1010. The cost of operation of the lamp is $3.00 per night for the operator, but we use him for other purposes.

The cost of maintenance of the lamp and the power runs about $1.00 per night making the total cost per night $4.00.

The lamp is located in a tower and throws the light directly into the yard and the men have become so accustomed to it that they do not want to get along without it. The people at Harrisburg learned about this lamp and after looking it over promptly installed one in their largest west bound classification yard. The capacity of the yard where the lamp is located is 3000 cars, we do not, however, always put that number over but we will average about 2200 cars a day.

The figures that were given regarding the number of accidents did not seem to bring out the point of the percentage of cars handled. I do not know the number of cars handled during the time they had those accidents or what percentage of the cars were damaged.

The Author: I have not the figures to show that. However, the yard was doing a good business and the reduction was not due to the fact that they were not doing any business. During the month of September they ran more cars over the hump than any month before in the history of the yard.

Mr. W. C. Copley: The lamp increased the efficiency of the yard and reduced the cost per car going over the hump a cent and a half, which would pay for the lamp in a very short time.

We have four separate and distinct hump yards at Altoona. The other points are not so large and we did not think it necessary to install search lights because on the east bound side the business is divided between two humps. We have a flaming arc lamp on the hump and ordinary arc lights in these classification yards. The west bound loaded hump has incandescent lamps with reflectors located along the tracks directed on an angle toward the body of the classification yard, which gives us a very good light and we do not feel justified in putting a search light in there; but where the business and the size of the

yard warrant the lamp, we have every reason to believe that it is the cheapest illumination obtainable.

I was over at McKees Rocks and saw the mercury vapor lamps in service and I must say they give a very nice illumination. One feature of the light is the absence of shadows. It is high enough to avoid objectionable shadows cast by the cars; but it is a question in my mind whether there was not a considerable waste of light due to the lamps being so high, in other words if the lights had been placed lower whether you would not have obtained as good if not better results at a very much less cost.

Mr. A. R. Raymer*: I would like to ask Mr. Copley if he can give us a statement of the reduction of efficiency of the search light during foggy weather; and approximately what was the percentage of reduction in accidents on account of the use of the lights on the hump?

Mr. W. C. Copley: I cannot answer the last question because we have always had lights on the hump, but on the empty humps where this search light is located, I would say the reduction in accidents due to the light is at least 25 percent. As to the fog I could not say, since a search light does not have a great deal more effect on it than any other light, of course you can see the rays of the search light through the fog, but it does not illuminate the yard.

The Author: What is the current consumption of the search light?

Mr. W. C. Copley: The lamp was installed in 1908 and has been in use continuously since that time. It is the General Electric automatic lamp No. 10653, Type H 4 B, amperage 35, voltage 45.

Mr. S. G. Hibben†: As the speaker presented this paper, I was making some mental notes on the comparison between the two chief schemes of yard lighting,—the high tower suspension of a few lighting units of large candlepower, and the

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†Illuminating Engineer, Macbeth Evans Glass Company, Wabash Building, Pittsburgh.

lower catenary or cable suspension of a large number of relatively small units.

If a few high-candlepower lamps of any sort were placed low, the results would undoubtedly be bad. If it were desired to merely outline objects against a light, this might be satisfactory, but although this scheme of low light sources is followed in street lighting, yet I would not advocate it for classification yard lighting. In street lighting the conditions are different in this one regard, that you do not care about distinguishing the details of an object, nor of its exact distance from you, expecting to come up to or against it, but you wish to have it outlined against a light background.

With the scheme as described, the light is well diffused over much the whole area of the yard, and there is not only lack of dark shadow, but better definition of all objects leading to better ability to judge horizontal distances.

The quartz lamp has among its good features the high efficiency of about 0.6 watt per mean spherical candlepower (compared to about from 0.76 to 0.80 watts per spherical candle for nitrogen filled, or type *"C"* tungsten lamps.) It also has good color value of bluish-white light for this class of service, and aside from the variations that occur at starting, it possesses self-regulation or is a "constant current" device. For instance the lamp used operates on 220 volts and I believe takes 3.5 amperes after reaching a steady point. Its starting current is large, characteristic of all mercury arcs, but after reaching equilibrium, in something less than 15 minutes, an increase in voltage will not cause an increase in current forced through the lamp. The life of the new types of lamps (tubes) often reach 5000 hours,—in rare cases 10 000 hours.

It is at a disadvantage on account of operating in multiple on direct current, and the wiring expense might be a considerable factor as against an installation of nitrogen filled series high voltage lamps, particularly in large yards requiring long runs of wire. It is also somewhat complicated for rough service, with its automatic tilting device for starting, its quartz-glass tube in which the tungsten terminal wires must be carefully sealed, and its balancing or regulating resistances.

The light-giving tube is only about 5 inches long, but is somewhat hard to equip with reflector, and I would like to ask the speaker what attempts have been made to prevent loss of light going sidewise outside of the yard.

Sulphur fumes around a railroad yard may cause rapid deterioration of metal reflectors or other parts of the lighting units and this must be considered. Perhaps the lamps placed high will be above these fumes.

The color of light from quartz arcs will probably not be best for penetration of fog and smoke, though this is a very minor consideration.

I think the speaker has described a very economical and excellent way of yard lighting, but perhaps there are other equally as good methods. The series tungsten lamps are worthy of consideration on account of maintenance costs, simplicity and reliability. Alternating current quartz arcs may also soon come into this field.

Mr. H. Kirschberg:* It is indeed a pleasure to have the opportunity of discussing the paper presented this evening by Mr. Morrison, especially in view of the fact that a considerable part of my own experience has been gained in the field of railroad illuminating engineering.

It is a safe statement to say that the railroads of this country do not as yet appreciate to what a great extent the correct solution of many of their lighting problems would be conducive to safe, economical, and efficient lighting. During the past seven years I have had occasion to dwell on this subject in published articles and papers before technical organizations on various phases of railroad illuminating engineering. The one particular phase discussed by Mr. Morrison is certainly worthy of as much consideration and time as may be necessary to obtain a correct solution, even if from the standpoint of revenue alone, for it is a well known fact that the main source of revenue to the railroad is its freight traffic. The carrying of passengers on many roads in this country is in reality maintained at a loss. Anything therefore, which will to any degree assist in the movement or improvement of freight traffic will show a larger earning capacity of the equipment.

*Treasurer, Lighting Specialties Company, Pittsburgh.

Mr. Morrison has presented his subject very well, and has shown that the problem of satisfactory illumination of a railroad yard, of any type, depends upon the ability of the engineer to analyze his problem in all of its various details. I have sufficient faith in the future recognition of this fact to be at present devoting all my time to illuminating engineering and I trust that the condition of street lighting will eventually be such as to occasion no further such well merited criticism as that to which Mr. Morrison has given expression. It has taken our own city of Pittsburgh about five years to discover the difference between a clear and an opal globe for an arc light.

Mr. Morrison is to be complimented upon his courage to install lamps at such great heights, and I well remember the interesting results obtained when the first lamp of the type now being used was mounted near the top of the coal tipple in the McKees Rocks yards and an initial test of illumination made thereunder. I have not been fortunate enough to see the complete installation but feel sure, from what I know of that test, that the results are fully as good as could be expected.

Mr. Morrison mentions an average illumination of 0.165 foot-candles throughout the yard with a minimum illumination of 0.015 foot-candles. It might be of interest to state here that bright moonlight under the best conditions or full moon, October skies and clear mountain air, approximates 0.04 foot-candles.

In conjunction with the problem of classification yard lighting I have always included the lighting of two other locations so closely connected both in location and importance with the classification yard, as to deserve consideration as part of the same installation, namely, the receiving yard and the track scale. The foregoing is apparent when it is considered that the car-riders are passing continually from the track scale zone to the classification yard zone and subjected to a certain extent to the receiving yard illumination before passing over the scale with their cars. The dangers to which the car-riders are subjected, especially in winter, under conditions of ice and snow, and the general tendency in favor of "safety first", should be sufficient in themselves to invite a study of this problem with-

out even a further consideration of the economies produced from the operating side.

As to fog, we have fogs of different kinds in Pennsylvania. I had occasion to make tests of signal lamps under conditions of fog. Starting from Altoona, if I went west, I would run into a fog in which the proportion of iron dust is very much in excess of what it would be if I traveled east, where the water vapor content in the fog is much higher. In the fog in which there is a high percentage of iron dust, red and orange, that is rays of greater wave length, penetrate much more easily than in fogs in which the water content is greater, in which the waves of shorter length, violet, indigo, blue and blue-green, penetrate with more ease. The color of the Cooper-Hewitt lamp, on the short ray side of the green, penetrates water fog more easily than the rays of the flaming arc of the usual yellow color.

Mr. W. D. Smoot:* Mr. Morrison has outlined for us another solution of one of the hardest conditions to be met in railroad yard lighting. It is a fact, that the quartz lamp located at unusual heights, compared with arc lamps or high wattage filament lamps, has a field of its own and fulfills certain requirements nicely. There are conditions, however, where the magnetite lamp furnishes sufficient illumination to be practical in its application to yard lighting.

I wish to cite as an example, an installation at Conway, Pa., located on Pennsylvania Lines West, where there is one of the largest hump yards in existence. To properly light these tracks, it was found advisable to use 6.6 ampere magnetite lamps, mounted about 32 feet above track level. We find there, that we do have shadows produced by cars, but the ends of the cars may be seen and distances judged quite satisfactorily. During a heavy fog, the lamps are practically useless, and as far as I am able to learn, the light is yet to be produced that will be entirely satisfactory in a fog.

It required 160 lamps to light these yards; 25 being devoted to four humps, or an average of 6 lamps per hump. This

*In charge of power plants, Allegheny Shops, Pennsylvania Lines West, Pittsburgh.

represents an actual power consumption of about 2534 watts per hump.

This installation has been cited simply to illustrate what would be a typical installation, where the quartz lamp might not be in favor because of the heavy feeders necessary to feed a number of lamps.

MR. W. C. COPLEY: Possibly I did not make my statements clear regarding the search light. We do not care anything about light in the yard other than to illuminate the ends of the cars beyond the hump, if the train men see those that is all that is necessary. This search light is located about the top of the hump on the side of the tower and the trainman does not necessarily have to look at the lamp at any time, but it does show where the car ahead stands and shows the line of track in the yard and allows the Asst. Yard Master to stand in his office and look out into the yard and tell what cars stand on each one of the tracks. We do not claim that the search light gives the same character of light as this system at McKees Rocks. It is not necessary. All we want is to light up the end of the car ahead, which we do by using the search light. And, as I have said, it increases the efficiency of the yard at the point where it is used and that is all we care for.

Light in the receiving yard was also mentioned. We do not care anything about light in the receiving yard, it is at the hump and the scale and in the classification yard that we want it, and technical criticism of the search light would not have much weight with us who are using it.

MR. A. R. RAYMER: How many feet above the tracks is the search light located?

MR. W. C. COPLEY: About 30 feet above the classification yard tracks or about 10 feet above the apex of the hump.

Referring to the complaint Mr. Kirschberg spoke of in another yard. That was somebody hunting something to complain about, for we went down and tried to get the fellow to point out where it had interfered with his work and he said he guessed possibly it was not as bad as he had thought. So the complaint was really without any foundation.

Mr. A. C. Cotton:† I viewed with considerable satisfaction this installation made by Mr. Morrison, and to me it is about the best thing I have seen in the way of classification yard lighting. It is quite probable that there are other schemes that can produce the same results, but at present I do not know exactly what they are.

Mr. Morrison suggested the possibility of using the nitrogen filled tungsten lamp some time in the future. In this connection, I might say that from experience other people have had, it would not be well to use a series tungsten lamp on a D.C. circuit, as that has proven more or less of a failure from an operating and maintenance standpoint. Inasmuch as Mr. Morrison's circuit is a multiple one, he probably would have no ill results with the lamp. The trouble with a D.C. series circuit is that if the filament breaks there is an arc set up across the break and the arc continues sometimes until not only the lamps but the fixtures are burned up. In an A. C. series system there is some part of the time when the current value passes through zero and at that time, of course, the arc is usually broken.

Going into the cost of installation, if we look at the cost of the accidents, $557 for some nine accidents, it would average about $62 an accident per month. If we capitalize this and give the lighting the benefit of preventing at least one $62 accident a month, it would amount to $744 a year, which would be interest, at 5 percent on about $14 880, or practically twice as much as Mr. Morrison spent for the entire installation. If we would consider the decreased number of accidents from nine to six may partly result from the lighting, or if we may consider that the decreased cost per accident from $62 to something like $10 may be due partly to the improved lighting, we can easily see that considerable money may be spent to get good lighting in these yards and result in not only reducing the total number of accidents but possibly the cost per accident. I take it that in a yard such as they had here previously, the collisions were sometimes quite violent and damaged not only the cars but the lading. On the other hand with good lighting,

†Instructor, Educational Department, Pennsylvania Railroad Company, Pittsburgh.

the collisions may have occurred but they did not occur with such violence and cars and lading were not seriously damaged.

The point was brought out about lack of space for placing lighting units. In the latest yard of any size that we have built in this vicinity, at Pitcairn, they did allow two spaces down the yard for lines of poles on which were placed series arc lamps. Outside of that installation, I do not know of any other on the Pennsylvania Railroad where there is any provision made for lines of poles, and most of our yards have lines of poles on the outside, so that half the light produced is thrown upon the surrounding hillsides and only half is obtained in the yard. I believe that in the majority of the yards we are forced to put the lighting in that way.

As to straddling the tracks with lighting towers, of course that might be done if there was space enough between the tracks, but there is not sufficient space. That is what we are up against. We have some yards where the clearance is very small indeed, probably due to the fact that the yards were built a good many years ago, and while there has not been any great increase in the width of cars, there has been a great increase in their length which has resulted in the cars coming closer together on curves.

Regarding the point brought out by Mr. Copley, I am sorry to hear him take the position that he does not care so long as he gets the light. That may be very true for present conditions and possibly for three or four years to come, but it occurs to me that from a physiological standpoint, sooner or later he is going to have a lot of men working in his yards whose eyesight will be impaired, and we as railroad men know that when a man's eyesight becomes seriously impaired he must be given a position where good eyesight is not a prime factor.

It is a fact that the City of Washington, D. C., has recently passed an ordinance prohibiting lights of high intensity to be hung low over the pavements by private individuals, simply for the reason that the people do not know enough themselves to protect their eyes. We see in Pittsburgh, the nitrogen filled lamps in front of moving picture shows, eight feet above the pavement, and you will walk up street, blink your eyes and hold your head down to get by them. The eye cannot accommodate that amount of light, and the eye cannot accommodate the light

from this search light. Whether you look at it or not the light is there and you are bound to get it in your eyes. Too much light is just as bad as too little. Investigation has shown that some classes of workmen have eye trouble due to too much light rather than not enough, hence it would seem that to remove sources of light of high intrinsic brilliancy from the normal range of vision would be the proper course to pursue.

MR. ELMER K. HILES: How frequently is it necessary to clean the quartz vapor lamp and how does it compare in this regard with the tungsten lamp?

THE AUTHOR: We started out cleaning them every two months and found that was not quite often enough, and we are now cleaning them every six weeks. I can tell on the train going by when it is time to clean them.

It is about the same proposition with the vapor as with tungsten lamps except that you have not as large reflectors to clean. It is not what it would be like to trim flaming arc lamps every 75 to 100 hours.

MR. A. C. COTTON: Is the 75 sq. ft. per watt calculated on the basis of classification yard alone and not on the surrounding yard?

THE AUTHOR: Yes, just the classification yard.

MR. A. C. COTTON: Of course, you have a great deal of that light in the surrounding yard, the south bound classification yard?

THE AUTHOR: The east bound classification hump is right across the yard.

MR. A. C. COTTON: You get a great deal of light on that, so that in reality you have a great many more square feet per watt than you actually show, if you consider the yard surrounding.

THE AUTHOR: Yes, as a matter of fact two towers are effective in the east bound yard.

MR. W. C. COPLEY: I am afraid our friend is putting too much emphasis on the damage caused by the search light. If it is going to affect the eyes of the people I do not know what will become of the people who run automobiles, for the light

from this search light is not any harder to look at than the average light on an automobile.

MR. H. KIRSCHBERG: The problem of overcoming the effect of glare of automobile head lights has received so much attention, by reason of the number of accidents which have occurred due to that cause, that the State of New York has passed laws compelling the automobile owners to put a diffusing medium before their lamps, or to install a smaller lamp in the head light to be used in passing through cities and towns. Similar laws have been passed in a number of cities in Pennsylvania, especially here in Pittsburgh. We have not as yet forced the application of the law to as great an extent as I hope it eventually will be.

The entire problem includes one which is not entirely physiological, that is the matter of danger to the eye, but also the psychological problem. This very same problem was brought out by the railroads in their investigation of locomotive headlights with special regard to the arc lamp headlights which were more or less forced on the roads by the action of the legislature in several states, whose members knew nothing of railroading and merely were desirous of obtaining the greatest amount of light on the track for the safety of those who might have occasion to cross it.

It is the most natural thing in the world to look at the brightest spot in the field of vision; in fact, it takes a conscious effort to look away from it. Every once in a while, however, the conscious effort lags a little bit and one is liable to allow the eyes to return to the bright source, thereby causing the diaphragmatic opening of the eye to contract, thus impairing the ability to see later on under intensities of light which must of necessity be lower. Then, there is what you might call the semi-hypnotic effect. There are some people who cannot look away from a bright light and cannot move during the time the bright light shines upon them. This is true to a large extent of the lower orders and is often the means of holding some of our smaller wild animals in something of a trance.

MR. HENRY S. PRICHARD:* With respect to the claim put forward as an argument against search light illumination, that

*Engineer, American Bridge Company, Pittsburgh.

it is only by conscious effort that men can refrain from looking at glaring lights, I ask whether it is the habit of locomotive enginemen to stare at the sun? If it is their habit so to do, I further inquire as to the comparative effect on their eyes of sun light and search light. On the other hand, if locomotive enginemen learn to avoid looking at the sun, can they not similarly learn to avoid looking at search lights?

It appears from the paper and its discussion that the suitable illumination of a railroad yard is not a difficult matter, per se, but is made very difficult by the failure of the engineers who lay out the yards to provide room between the tracks for lamp posts. If such is the case, the fact should be emphasized to influence engineers to consider this phase of the subject in laying out new yards. To leave room for posts in yards where space is limited will, of course, to some extent, curtail yard room but, on the other hand, if it tends to facilitate the use of the yards at night, the net result may be beneficial.

Mr. H. Kirschberg: I have heard of a number of instances of beggars on the streets of New York sitting pationtly all day with the sign "I am blind" and to prove it, looking at the sun. In a number of cases, the result eventually justified the sign they carried.

Mr. W. C. Copley: The "riders" cannot see the search light when they are riding the cars out because their backs are toward it, and when the men return to the hump they are riding in a closed car known as the "pick up" and they could hardly look at it if they wanted to.

The Author: Answering some of the questions raised, I would say: no serious attempt has been made to confine the light inside the yard and in the case of at least five towers, one half the light is ineffective as regards the classification yard. We have just installed for trial a lamp with a deep reflector on the side away from the yard.

The number of cars over the hump in the months for which damage figures were given is as follows: April, 9750; June, 14 174.

CONSTRUCTION FEATURES OF THE NORTH SIDE RESERVOIR

OF THE

WATER WORKS OF THE CITY OF PITTSBURGH

By E. E. Lanpher* and J. S. Cole†

The new North Side reservoir, commonly known as Cabbage Hill reservoir, of the Pittsburgh Water Works, is located in Shaler Township, about six miles from the point section of Pittsburgh and about one-half mile north of the Allegheny River, between Etna and Millvale Boroughs. The elevation of its flow line is 275 feet, Pittsburgh datum, or 971.52 feet Sandy Hook datum, and is identical with the flow line elevation of the lower Highland Park reservoir which supplies that portion of the central city along both rivers, and the entire South Side.

Generally speaking, the reservoir is of 160 million gallons capacity, with a water area of 17 acres and a water depth of 38 feet. It has been built by the cut and fill method, three sides being built of rolled embankment, the remaining side being entirely in cut, surrounded by a reinforced concrete retaining wall along a public roadway. The reservoir is divided into east and west basins by a reinforced concrete dividing wall 18 feet high, containing the inlet conduit which connects the main, or inlet and outlet gate house in the northerly embankment with distribution or secondary gate house in the southerly slope.

The objects of the reservoir are: First, to replace the old, small and unsafe Troy Hill reservoir in the supply system of the North Side (formerly Allegheny): and, Second, to act as an equalizer in conjunction with Highland No. 2 Reservoir; the

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main distribution feeder mains from both reservoirs to be cross-connected by a 48 inch steel main under the Allegheny River.

HISTORICAL AND CONTRACTS

In 1896 the former City of Allegheny laid a 60-inch steel water main from its pumping station at Montrose on the Allegheny River, a distance of about 8.6 miles, to the Troy Hill reservoir. At Etna this main deviated north from the river over a divide and thence back to the river bank near Millvale.

The new North Side reservoir is constructed on this divide, so that the toe of the northerly embankment is bounded by the water main. Allegheny had intended to construct such a reservoir about one-third mile north, and about 100 feet higher than the present reservoir, and installed two *Y's* and valves on this main about one-half mile apart and looking toward the higher elevation. These *Y's* and valves were of great value in the connecting of the new reservoir to the supply main, without interfering with the water supply, inasmuch as the 60-inch main was the sole source of water supply of the North Side.

The reservoir is constructed from funds provided for at the November bond election of 1910. Designs and specifications were prepared in the Division of Engineering and Construction of the Bureau of Water, and contract was awarded upon the unit price basis, July 6th, 1912, to the John F. Casey Company upon the schedule given in Table No. 1 on pages 671 to 673 inclusive.

EXCAVATION AND EMBANKMENTS

Work of clearing the site was started July 20, 1912. Preparatory to embankment work, the entire site of 24 acres was cleared of all vegetable growth and the top soil removed to storage piles. Good foundation for embankment was found in most places at a depth of about 18 in. All embankment material was obtained from excavation in the basin and consisted mainly of first class clay of several shades, and of easily broken stone of shale formation, although in some cases low grade dynamite was used to facilitate digging. Most of this shale disintegrated rapidly when exposed to the atmosphere. A mixture of the clay and shale spread in layers of 6-in. or less, and rolled with grooved rollers of two tons per foot produced

Table No. 1. Schedule of Contract Items.

Item No.	ITEM	Estimated Quantities	Unit	Unit Price	Total Amount	WORK INCLUDED. (All Labor, Material and Equipment furnished by Contractor.)
1.	Top Soil Excavation and embankment	13,000	Cu. yd.	$1.00	$ 13.000	Stripping of top soil where excavation and embankment are to be made, storing of the top soil in piles and its re-excavation and placing in embankment or where required. Includes only material excavated twice and placed in embankment.
2.	General Excavation	353,000	Cu. yd.	.39	137,670	Clearing, grubbing and excavating of the reservoir and all structures to the sub-grades, the disposal of this material, the furnishing, placing and removing of all sheeting and bracing necessary, together with the drainage of all work.
3.	Excavation in trench	22,500	Cu. yd.	1.75	39,375	Excavation and back-filling for all pipe lines, conduits, drains, catch-basins and miscellaneous structures and the reconstruction of any pipes, drains, culverts or water-courses encountered, not included under "General Excavation."
4.	Embankment	275,000	Cu. yd.	.27	74,250	Building of the embankments under the floor of and surrounding the reservoir.
5.	General Filling	50,000	Cu. yd.	.50	25,000	Placing of general fill where ordered or shown on the contract plans.
6.	Seeding	10	Acre	100.00	1,000	Furnishing and sowing of all grass seed on the surfaces of embankments and fills, and wherever called for.
7.	Sodding	4,200	Sq. yd.	.25	1,050	Furnishing and placing of all sod on top of the loam, and along the edges of embankments, and where called for.
8.	Gravel	9,100	Cu. yd.	2.00	18,200	Furnishing and placing of the gravel lining under the revetment on the reservoir slopes, in the embankment, around drains, etc.
9. 13.	Concrete in floors Reinforced concrete in floors	18,400 2,500	Cu. yd. Cu. yd.	5.80 7.00	106,720 17,500	Concrete in the floor and on the slopes of the reservoir, the steps and floor and roofs of gate chambers.
10. 14.	Concrete in Walls Reinforced concrete in Walls	2,300 2.700	Cu. yd. Cu. yd.	7.75 8.00	17,825 21,600	Concrete in the walls of gate houses, valve chambers, venturi chamber, retaining wall, and places requiring considerable form work.

Table No. 1.—Continued.

Item No.	ITEM	Estimated Quantities	Unit	Unit Price	Total Amount	WORK INCLUDED. (All Labor, Material and Equipment furnished by Contractor.)
11.	Concrete in Trench	600	Cu. yd.	7.00	4,200	Concrete about steel and cast iron pipes, in the bottom of catch basins and miscellaneous filling.
12.	Concrete in conduits and drains	3,300	Cu. yd.	12.00	39,600	Concrete in the drains, the inlet and outlet conduits, and all man-holes and other chambers connected therewith, including copper expansion joints.
15.	Concrete in Coping	2,525	Lin. ft.	3.00	7,575	Building of the coping and curbing around the reservoir.
16.	Concrete in Curbing	2,760	Lin. ft.	1.50	4,140	
17.	Concrete Fence	3,550	Lin. ft.	3.00	10,650	Building of the concrete fence, including reinforcement around the reservoir.
18.	Steel Reinforcement	668,000	Lb.	.025	16,700	Placing of all steel reinforcement except for concrete fence, Item 17.
19.	Brick Masonry	150	Cu. yd.	10.00	1,500	Brick masonry, either laid dry or with mortar, in man-holes, catch basins, gate chamber, etc.
20.	Waterproofing slopes	310,000	Sq. ft.	.11	34,100	Placing of all waterproofing.
21.	Waterproofing floors	110,000	Sq. ft.	.075	8,250	Placing of all waterproofing.
22.	60 in. Steel Pipe	2,075	Lin. ft.	20.00	41,500	Making, transporting, laying and connecting up complete, all steel pipes, including caps, flanges, gaskets, bolts, manholes, handholes, air valves and water blow-offs and the testing and repairing of completed lines.
23.	Steel Pipe removed	125	Lump		3,000	Cutting and removing of the present pumping main and the temporary bulkheading of the line, together with the removal of all water from the trench.
24.	Cast Iron Pipe	22	Ton	40.00	880	Laying of all cast iron pipe together with the necessary lead, yarn nuts, bolts, gaskets, etc., needed in making the joints.
25.	Cast Iron Specials	16	Ton	100.00	1,600	
26.	Sluice gates 3½x6	6	Each	870.00	5,220	Placing, testing and painting of the sluice gates and frames, anchorages or templates, operating stands, stems, guides and all appurtenances.
27.	Sluice gates 2½x3	2	Each	540.00	1,080	
28.	Sluice gates, 60 in. circular	2	Each	690.00	1,380	

29.	Gate Valve, 48 in.	2	Each	1,035.00	2,070	Placing of all gate and check valves, together with gaskets, bolts and appurtenances necessary.
30.	Gate Valve, 12 in.	2	Each	38.00	76	
31.	Gate Valve, 8 in.	8	Each	23.00	184	
32.	Gate Valve, 6 in.	6	Each	16.00	96	
33.	Check Valve, 12 in.	2	Each	80.00	160	
34.	Check Valve, 6 in.	2	Each	20.00	40	
35.	Indicator Stands	8	Each	110.00	880	Placing of indicator stands and wheels for the operating of all valves.
36.	Venturi Meters	2	Each	2,700.00	5,400	Erection of meters, registers and appurtenances on the sixty (60) inch steel pipe lines.
37.	Manhole and Catch Basin Frames and Covers	40,000	Lb.	.03	1,200	Placing of all manhole and catchbasin frames and covers.
38.	Stop planks and lifters		Lump		500	Yellow pine stop planks and their lifters.
39.	Cast Iron Miscellaneous	90,000	Lb.	.04	3,600	Placing and painting of all cast iron necessary for the work and not included under other items.
40.	Misc. Wrought Iron and Steel	13,000	Lb.	.10	1,300	Placing and painting of the structural steel and wrought iron for ladders, ladder bars, manhole steps, steel pipe used for supports of piping, the angle frames and gratings in gate houses and all other miscellaneous wrought iron or steel work, etc., together with all washers and rivets necessary for erecting this material.
41.	Indicating and Recording gages	2	Each	300.00	600	Installation of the indicating and recording gages including piping and float tubes in the gate house.
42.	Roadways	2,900	Sq. yd.	200.00	5,800	Building of the roadways.
43.	Concrete Sidewalks	11,800	Sq. ft.	.15	1,770	Building of all concrete sidewalks as shown on the plans.
44.	Gas piping		Lump		750	Laying of the exterior gas pipe system including fittings.
45.	Tile Pipe, 6 in.	4,500	Lin. ft.	.20	900	Construction of the vitrified pipe drains.
46.	Tile Pipe. 8 in.	2,200	Lin. ft.	.25	550	
47.	Tile Pipe. 12 in.	650	Lin. ft.	.40	260	
48.	Tile Pipe, 18 in.	1,700	Lin. ft.	.75	1,275	
	Total				$681,976	

a very hard, impervious embankment, but it was necessary to pass the roller over each layer at least six times to thoroughly compact the soil, and to further break the small stones. (There are no stones in the embankment larger than 4-in. in diameter.)

Three steam shovels with 3, 1½, and ½ yard dippers respectively and a McMyler crane were used in excavating, the larger shovels working efficiently in the shale. Four contractor's engines and fifty dumping cars, of 4 yards capacity, were used in conveying the material to the embankments. An engine operated spreader, two road graders and four 16-ton rollers were used in spreading and rolling the embankments. The maximum yardage excavated and rolled in embankment in one day of 11½ hours, was 3500 cu. yd.

The embankments have a slope on the outside of 2 to 1 for a height of about 20 ft., where there is a 5-foot berm. Above this berm the slope is 1¾ to 1 for a height of 20 feet. On the inside, the slope is uniform at 2 to 1 from the bottom to the top, the height being about 42 feet above the floor of the basins. The outside of the embankment was scored and covered with 6 inches (measured vertically) of top soil, which is seeded and sodded. This top soil was dumped from the top of the embankment, graded and rolled, a horse operated roller being used.

The top of the embankment is 15 ft. wide, while the maximum width of the foot of the embankment is 185 ft.

STEEL PIPE AND CONNECTIONS

In order to maintain the supply through the single 60-inch main and make the difficult connections to the main gate house, about one-half mile of 60-inch riveted steel main of ⅜-in. plate was laid parallel to, and connected to the *Y's* left in the old main. From these two mains two 60-inch steel inlet pipes and two 60-inch steel outlet pipes were installed to the main gate house in the northerly embankment. Both 60-inch mains are equipped with Venturi meters (30-inch diameter of throat) consisting of cast iron up-stream ends, bronze throat pieces and reinforced concrete tail pieces. These tail pieces were built in place and at ten days were subjected to a 90-pound pressure test, showing no signs of leakage.

Fig. 1. North Side Reservoir Looking Northeast, Showing Concrete all Placed.

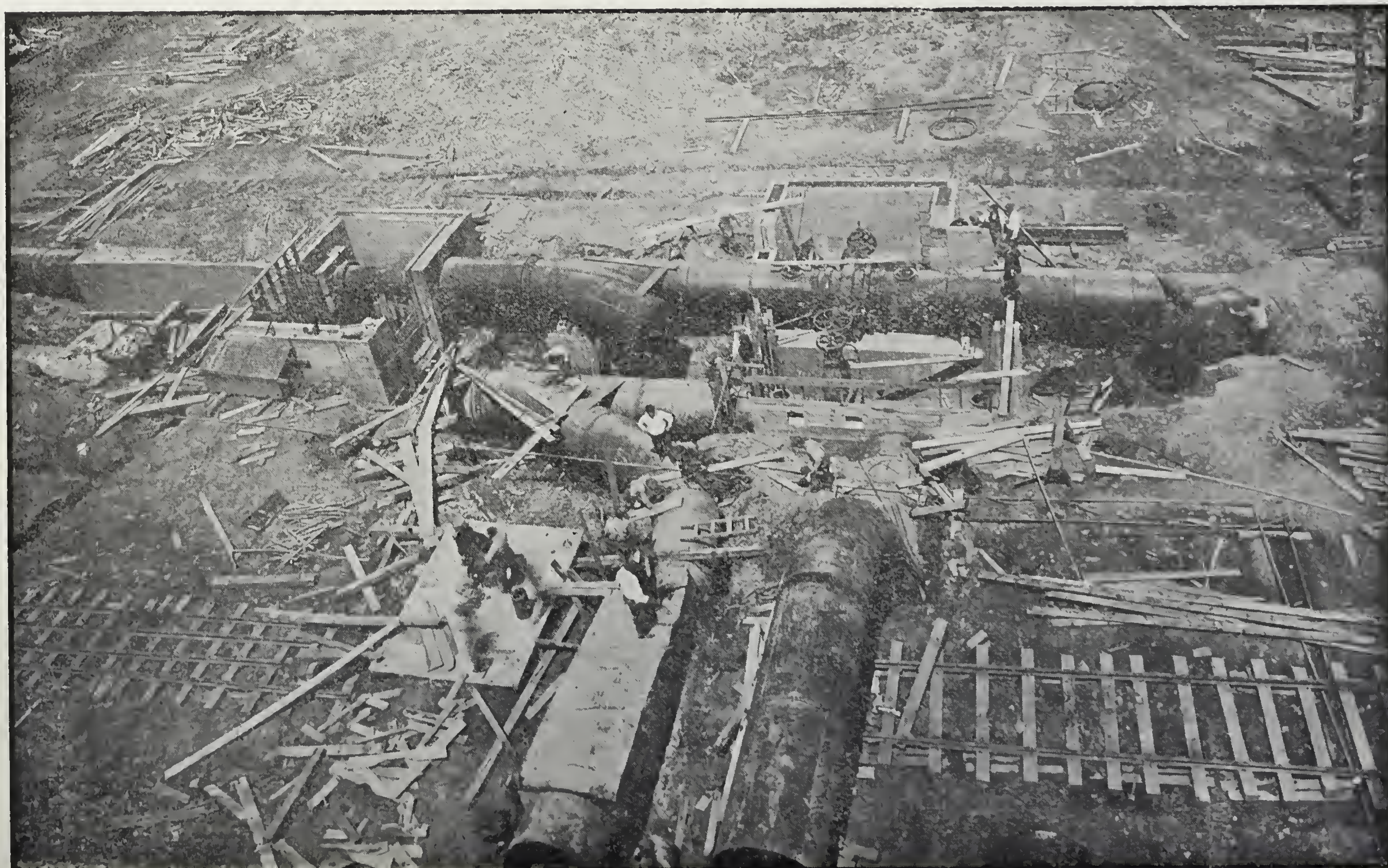

Fig. 2. 60 inch Steel Pipe Connections at Gate House.

The 70-ton traveling crane was used in connection with all of the steel pipe work, no tripods being used. Even the excavation was done by this crane with an orange peel bucket. A 300-foot length of 60-inch pipe was laid in one day, the major portion of it being riveted. At one time it became necessary to shut off the water in the old main, cut out the rivets of three joints, remove 125 feet of the pipe, replace a portion of this pipe with one section containing a bulkhead and rivet this section to the pipe in place; all of which was done in four hours.

Riveted steel *Y's* and *Tees* of ½-inch plate were used in place of the usual cast iron specials.

MAIN AND SECONDARY GATE HOUSES

The main gate house foundation is a reinforced concrete structure, 42 x 38 feet in plan, extending from bed rock to the top of the northerly embankment. Water enters through the two inlet pipes at elevation 242.5, and rises in the inlet wells and flows over weirs at elevation 271 into two inlet chambers controlled by stop planks, thence through the main inlet chamber again controlled by stop planks to a 7-foot reinforced concrete conduit through the embankment and directly across the reservoir to the secondary gate house in the southerly slope. The secondary gate house is a well 24 ft. 6 in x 11 ft. 3 in. in plan, into which the water enters at reservoir floor elevation, rises to elevation 263.90, where it is passed through 5-foot circular sluice gates to distributing conduits in both basins. The water again re-enters the main house through two 5-foot reinforced concrete conduits, passing directly through the gate house to the two outlet pipes. Both outlet channels through the gate house are controlled by 6 ft. x 3½ ft. sluice gates in addition to stop planks on both sides of each sluice gate.

The main gate house is so arranged that water may be passed from the inlet pipes to the inlet chambers, to the outlet chambers and outlet pipes, without entering the reservoir. Water may be drained from either basin to the main drain through 3 ft. x 2½ ft. sluice gates in the outlet chambers.

The main gate house was poured in two horizontal sections and five vertical sections, and contains approximately 800 cubic

yards of concrete mixed in a 1-yard batch mixer, electrically operated, all material being handled by the traveling crane.

The superstructures of these gate houses are not included in the present contract.

DRAINAGE SYSTEM

In the main gate house a waste weir at elevation 275 is provided against overflowing, the water being carried to the main drain which is a 36-in. circular conduit approximately

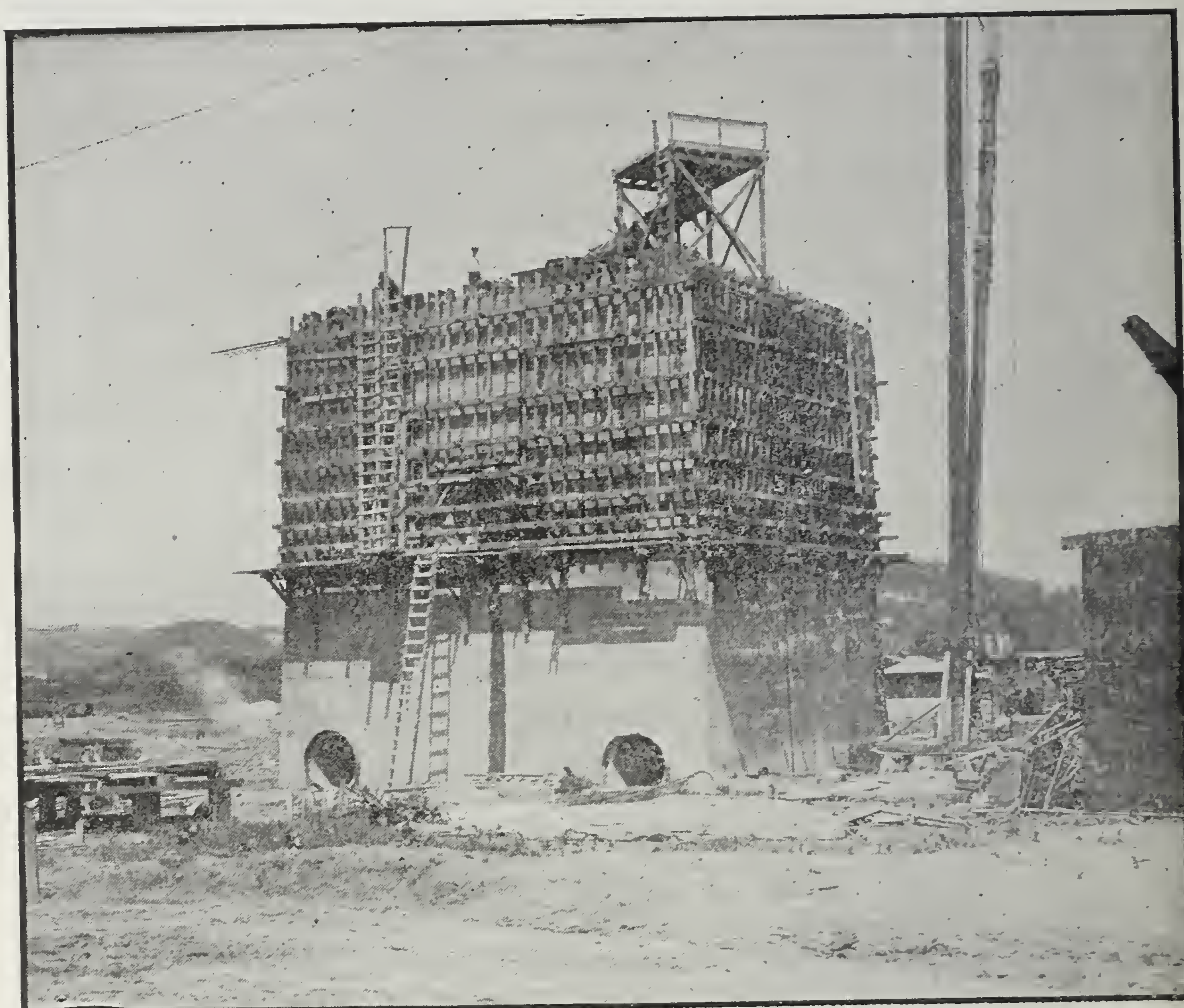

Fig. 3. Gate House Showing Forms on Upper Section.

2300 ft. long, running parallel to the main pipe lines to a small stream discharging into the Allegheny River. Into this drain also discharges surface water from a 3 x 2 foot egg shaped concrete drain, extending along the roadways on the southerly and easterly sides and a 12-in. and 18-in. tile drain extending along the westerly and northerly sides of the reservoir. Along the southerly, or hillside, portion of the reservoir, between the Friday Avenue wall and the roadway, a ground water cut-off

drain was installed consisting of a 6-in. open joint tile pipe in a 30-in. trench, the trench being filled with gravel to the surface. This tile pipe is at elevation approximately 255, or about 18 ft. above the floor of the basins, and failed to cut off all ground water as was shown when excavation proceeded to grade. This condition caused the construction of shallow diagonal drains under the floor system along the easterly and southerly slopes as nearly perpendicular as possible to the direction of ground water flow as determined by observations from a system of test wells. These diagonal or herring-bone drains carry the water to main collector drains along the toe of the southerly slope, and thence to two 8 in. main drains under the dividing wall and through the embankment to the waste drain in the gate house. All of the collecting drains consist of 4-in. and 6-in. open joint tile surrounded by gravel, all covered by a 12-in. concrete cap which forms a foundation for the floors. The 8-in. drains are surrounded by concrete to prevent upward pressure on the base of the dividing wall.

Steel forms were used for the 36-in. main drain and part of the egg drain, and both drains were poured in two sections, except where the main drain was reinforced near the gate house. In the deep trench of the cut-off drain an *A*-frame movable crane with hoisting drums was used to remove excavated materials. Concrete in drains was mainly hand mixed. These drains were constructed mainly in cold weather, making it necessary to heat the sand and gravel, and to maintain fires in the trenches.

FRIDAY AVENUE RETAINING WALL

The reinforced concrete retaining wall, extending for 875 ft. along the southerly side of the reservoir and holding in place a public roadway, is built at the top of the 2 to 1 slope and varies in height from 2 to 21¾ ft. The heel of the wall is tied into a 2 × 3 foot egg shaped drain for stability. The vertical section of this wall is 18 in. thick. The foundation extends 2 feet in front and in the higher sections 9 feet back of the face of the wall.

The vertical reinforcing of the higher sections of the wall consists of ⅝-in. rods on 16-in. centers from the top to the

base, 5/8-in. rods on 8-in. centers from a point 10 feet below the top to the base, 5/8-in. rods on 4-in. centers from a point 12 feet below the top to the base, and in addition, 3/4-in. rods on 10-in. centers through the base and the top of the egg drain, and 5/8-in. rods on 12-in. centers extending from the base both sides of the egg drain, with additional short rods at construction joints.

Fig. 4. Dividing Wall and Conduit.

The base of this wall was constructed in 8 foot sections because of interference of the bracing that held the roadway in place, while the wall proper was built in 48 foot sections, or from one galvanized plate expansion joint to another.

After this wall had been practically completed and the slope trimmed, a slippery clay was exposed, showing that a general movement of the wall would probably follow the backfilling. A large toe pier or buttress was therefore constructed below and in front of the base of the retaining wall and ex-

tending to the rock, increasing the stability of the wall against sliding from 0.98 to 1.50 as computed from Baker's formula with a coefficient of 0.25 for the sliding of clay on clay. By working the concrete dry a close joint was made between the toe pier and the base of the wall, no sulphur, lead or wedges being used.

Concrete for the wall and toe pier was mixed along Friday Avenue in a ½ yard batch mixer; the *A*-frame traveling crane being used in the handling of the forms and in the backfilling.

DIVIDING WALL AND CONDUIT

The original design of the reservoir provided for an earth dividing embankment surmounted by a 7-foot reinforced concrete inlet conduit extending between the two gate houses. Inability to obtain sufficient clay to mix with the shale for outside embankment purposes caused the substitution of a combined dividing wall and conduit for the dividing embankment and circular conduit.

The conduit wall is a triangular conduit of an area equivalent to a 7-foot circle, supported on two legs or cut-off walls extending from 5 to 9 feet below the floor to bed rock, all surmounted by an 18-inch wall about 5 feet high, making the height of the conduit wall 16 feet above one basin floor and 18 feet above the other basin floor. The sides of the triangular conduit are 20 inches thick, reinforced with ⅞-in. diamond bars on 9-in. centers, extending from the legs to the surmounting walls and ½-in. diamond bars on 12-in. centers at both surfaces. The base of the triangle is designed as a beam with the same reinforcement as the sides. The surmounting wall is designed as a cantilever. Copper expansion joints are used in the legs and floors.

This conduit wall was built in 58½ ft. sections; the legs, the conduit floor and the sides with the surmounting wall being built at separate pourings. It being practically impossible to work the concrete in the conduit forms, two air hammers were kept constantly but gently hammering the forms during the pouring, resulting in a thoroughly compacted concrete of smooth finish.

All forms and material for the dividing wall and conduit were handled by the cableway.

That portion of the inlet conduit from the main gate house to the conduit wall is a 7-foot circular, reinforced, concrete conduit for a distance of 40 feet to a vertical well, which forms the junction of the circular section and the triangular section of the inlet conduit.

The reinforcement of the circular conduit consisted of ½-inch rods on 6-inch centers running longitudinally, and ½-inch rods on 4-inch centers running transversely, except in the outside layer of the reinforcement in the bottom where ½-inch rods on 24-inch centers running transversely, and ½-inch rods on 4-inch centers running longitudinally, were used.

The concrete for the circular conduit was mixed in a ½-yard batch mixer, while the concrete for the vertical well was mixed in the central mixing plant, and placed by means of the cableway.

CENTRAL CONCRETE MIXING PLANT AND ITS SUPPLY AND DISTRIBUTION PLANT

All the sand and gravel used in the construction of the reservoir was dug from the Allegheny River in the vicinity of Hoboken, from which point it was transported in barges to Millvale, where the contractor installed a hoisting plant. The material was taken from the barge in a clam shell bucket and dumped into an elevated storage bin containing compartments for coarse gravel, fine gravel and sand. From this bin it was taken to the reservoir, a distance of 1¾ miles by a group of six 5-ton auto trucks, each truck making from 18 to 20 trips per day of 11 hours. The cement was received at a siding adjacent to the Millvale storage bin, and transported to the reservoir in a 5-ton flat-bed truck. During the summer of 1914, these trucks were operated double shift, or 22 hours per day, in order to maintain a supply of materials at the reservoir site. From the fleet of 7 trucks, it was found necessary to hold one truck each day in the shop for overhauling.

At the reservoir, the supply bins and the cement house were built on the southerly slope between the foundation of the

secondary gate house and the Friday Avenue wall. These bins held approximately 400 yards of concrete gravel, 200 yards of sand and 200 yards of coarse gravel. Storage was provided for two cars of cement in the cement house and one car on the platform. Sand and gravel were dumped from the trucks directly into the bins. The cement was dumped on the Friday Avenue platform and hand handled to the chute leading to the cement house.

An electrically operated 1½-yard batch mixer was installed on the secondary gate house foundation directly in front of the storage bins. The sand and gravel from the bins were controlled by shear gates directly above the mixer hopper, while the cement was placed in a vertical chute directly over the hopper, and controlled by a slide gate. The hopper was standardized for 1 yard of concrete. During the busy season 1 yard of concrete could be turned out of the mixer every minute, although the average time of mixing was about 1½ minutes; this, of course, was for wet concrete used in walls and all flat work. The dry concrete used on slopes required about 2¼ minutes for mixing each batch.

The mixer discharged directly into shear gate buckets on flat cars, or to cradle cars. Three contractor's locomotives were required, during the time of the laying of the floor and slope blocks, to transport the concrete from the mixer to the crane.

A stationary cableway was used in the construction of the dividing wall and conduit, and the well in the northerly embankment, also for general transportation purposes from Friday Avenue, including the transporting of the steel reinforcement and concrete forms. The head tower is 50 feet high, located on the southerly side of Friday Avenue, and the tail tower is 45 feet high, located on the gate house in the northerly embankment. The distance between towers is approximately 850 feet.

RESERVOIR LINING

The lining of the reservoir floor and of the slopes up to the revetment consists of two 4-in. layers of concrete, the joints overlapping 8 in. instead of the usual method of overlapping from center to center of blocks. The lining of the slopes above

the revetment drain consists of a 4-in. layer of concrete covered to a depth of 12 in. with large gravel, upon which rests a 6-in. layer of reinforced concrete, the waterproofing and a 4-in. surface layer of concrete. The floor blocks are 10 ft. square while the blocks on the slopes vary from 8 × 10 ft. to 16 × 38 ft. the larger blocks being in the 6-in. reinforced layer.

Fig. 5. Central Mixing Plant.

Waterproofing of the slopes consists of four $\frac{1}{16}$-in. layers of asphalt and three layers of 8-oz. saturated burlap laid alternately, between the layers of concrete, while in the floors three layers of asphalt and two layers of burlap in 18-in. strips were used at the floor joints only in such a manner that the waterproofing overlaps the joints of both layers by 5 inches. All joints were treated with asphalt either by mopping or by pouring the spaces left by the ¼-in. steel plates used as forms. The three-ply waterproofing is about ⅜ in. thick, while the two ply waterproofing is about ¼ in. thick.

All concrete used below the revetment was mixed at the central mixing plant, transported in 1-yard batches in shear gate buckets on flat cars, lifted from the flat cars by the 70-ton crane and dumped into the forms. A few of the blocks above the revetment were placed in this same manner; a few such blocks were also built from concrete mixed in a ½-yard mixer on top of the embankment dumping directly into the forms; but the major portion of these blocks were built from concrete mixed at the central plant, conveyed in yard cradle cars along the top of the embankment and dumped into the forms. The concrete for the floor blocks was of a wet mix, while the concrete for the slope blocks was much dryer.

On the slopes the usual system of pouring alternate blocks was followed. On the floors the concrete was laid in rows extending from one side of the basin to the opposite side; the longitudinal forms consisting of 4-in. × 6-in. stringers, while the transverse forms were ¼-in. × 4-in. steel plates set in the stringers and the points of the preceding row of blocks. The concrete was finished with straight edge and wooden trowels. In a day of 11 hours, 488 yards of concrete were placed in floor blocks and finished.

The distributing conduits, which extend along the southerly slopes of both basins were built from concrete mixed in the ½-yard mixer working along Friday Avenue. A section of this conduit is in the form of a trapezoid, the top of which is horizontal, the bottom of which is the upper layer of the floor system on the 2 to 1 slope, and the sides of which are vertical. Circular openings are provided in the top of the conduit, to provide for circulation of water near the secondary gate house.

The asphalt was heated to 400 deg. Fahr. and applied with ordinary cotton mops. In three-ply waterproofing the burlap was lapped 13 inches, the width of burlap being 39 inches.

All concrete used in the construction of the reservoir was of 1 : 2 : 4 mix, except in negligible cases, such as manholes, catch basins and gate vaults.

The responsibility of the reservoir lies with Mr. Joseph G. Armstrong and Mr. Robert Swan, former and present Directors of the Department of Public Works; Mr. Charles A. Finley,

Superintendent of the Bureau of Water; Mr. C. O. Daughaday and Mr. John M. Rice, Division Superintendent and Assistant Engineer respectively, of the Division of Engineering in charge during the design and first four months of construction work; Mr. E. E. Lanpher and Mr. John S. Cole, Division Superintendent and Assistant Engineer respectively, of the Distribution Division in charge since November, 1912.

DISCUSSION.

Mr. L. P. Blum: I would like to ask what Mr. Lanpher considers the advantage of lapping the two layers of concrete only 8 in. instead of lapping them half their length, as is usually done.

Mr. Lanpher: Mr. Rice was the original designer of that method and I will ask him to answer your question.

Mr. J. M. Rice: We adopted this design from experience gained in the construction of the Pittsburgh Filtration Works. During the first season of construction the floor which was of two layers, each four inches thick, was put in with the upper blocks breaking joints at the center of the lower layer blocks, and after the winter had passed, we found that the upper blocks had broken just over the joints in the lower layer. In the endeavor to avoid this next season, we brought out the construction used here, i. e. offsetting the vertical joints in the upper and lower layers from 6 to 8 inches and this proved effective.

The explanation for the cause of the cracks offered is that the contraction in the lower blocks during the cold weather had been sufficient to break the upper blocks and by lapping the joints a small amount, we did not get that effect as the adhesion of the surface in contact was less than the strength of the upper layer of concrete, and thus sliding instead of cracking occurred.

In spite of the precaution taken to secure water tightness and the adoption of a water--proofing membrane, this reservoir, compares very favorably in cost per million gallons with reservoirs of similar size as shown in the following tabulation of costs of some large basins constructed in the United States.

Reservoir	Location	Capacity in Million Gallons	Cost	Cost per Million Gallons.
Queen Lane	Philadelphia, Pa.	383	$1,188,000	$3100
New Roxborough	Philadelphia, Pa.	147	524,000	3600
Settling Basins	Cincinnati, Ohio	330	1,276,000	3900
Service Reservoir	Minneapolis, Minn.	93	442,000	4750
Prospect	Rochester, New York	110	554,000	5000
Northside	Pittsburgh, Pa.	150	676,000	4100

Mr. J. A. Ferguson: There might be questions asked as to why only the sides of the basin floor were reinforced? And just how the reinforcement was tied together, where the bars crossed each other; whether the reinforcement was put on the top or bottom of the slab and whether it is intended simply to tie the concrete together or to act to distribute the water pressure over the area of each particular block or slab of concrete?

I do not have any remarks to make on the subject of the reinforced concrete, except to say that in almost all cases where temperature changes are likely to take place it has been found sufficient that the average amount of reinforcement called for by those who write papers and publish their designs is a little too low for practical purposes. In many cases I have observed, especially in retaining walls, cracks occur where we did not make joints in the construction. That brings me to a question which I would like to ask, how much reinforcement was placed longitudinally in the retaining wall and how often were expansion joints placed in it?

Mr. E. E. Lanpher: I presume the first question is as to the reinforcement in the slab at the upper end of the slope, where the reinforcement was necessary due to the loose gravel of the revetment. This reinforcement was placed at the bottom of the slabs. Except over the revetment the floor blocks were laid on good foundation.

The walls on the Friday Ave. side were constructed in 48 ft. sections; the dividing walls in the basin were constructed in 58½ ft. sections; the base of the retaining wall was constructed in 8 ft. sections, but that was because of the interference of the timbers that held Friday Ave. in place. The longitudinal bars of the Friday Ave. wall were ½ in. rods on 24 in. centers.

Mr. H. H. Rankin: Has any study been made of the amount of evaporation on a reservoir of this size, as to whether

it would pay to make it deeper and with not so much surface. Have you any data as to what the evaporation amounts to?

Mr. E. E. Lanpher: There have been any quantity of observations made as to evaporation. There were no extended studies or observations as to evaporation applying particularly to this case. For such a reservoir as this it is largely a construction problem, depending on contours. You have to make the reservoir deep enough to get a balance between cut and fill. Every other consideration is dwarfed in comparison with that. To dig deeper and then to waste the soil is the thing to be avoided.

Mr. S. L. Fuller: One of the most interesting points that we discovered in the course of the construction work was in relation to the waterproofing. This consisted of three plies of saturated burlap mopped on with hot asphalt. The specifications said "all surfaces receiving waterproofing shall be clean, dry and smooth." The word "dry" in relation to setting concrete was subject to the decision of the Inspectors and naturally was an open point for argument as in order to keep the work moving, we desired to lay the waterproofing as soon as possible while the Inspectors held out for strictly dry surfaces. We had occasion to remove one of the top blocks and much to our surprise and gratification we found that while the layer of waterproofing which had been mopped on to the 24 hour old concrete had no adhesion to it at all, yet the top block which had been poured wet on to the asphalt could not be separated from it. We then made several experiments and we found that the best bond between the asphalt and concrete was obtained when the asphalt was mopped on as soon as the concrete had set so that it could be walked on without injury. The theory we advance is that as soon as concrete starts to set, it starts to "dust" and by applying the asphalt practically before this starts, we avoid the thin layer of dust which it is impossible to remove and which prevents the close adhesion of asphalt to concrete.

Probably the most remarkable thing about the job was the speed obtained in laying the four inch floor slabs. Through a carefully designed concrete plant with one Ransome 40 cu. ft. mixer, motor driven, we were able to average 375 cu. yds. per day

for a period of four weeks, the maximum day's output being 489 cu. yds. Concreting was not started until June 17th and since then we have put in approximately 30,000 cu. yds. All of the material for this was hauled by five, five-ton Pierce Arrow motor trucks which we found most economical in operation. These we worked 24 hours a day and they have hauled something over 70,000 tons of material over a distance of 1¾ miles, the last ¾ mile being all up a 4 to 6 percent grade.

A MEMBER: What about the economy of the hauling by motor trucks as compared with horse and wagon?

MR. S. L. FULLER: It would have taken wagons a day, to say nothing of "snatching" the teams up the hill. It is impossible for a team to make more than six trips a day with a two yard wagon. That means 11½ hours. The economy of the motor truck was marked. We cut down the haul by probably half over what we could have accomplished with teams, and it would have been impossible to complete the reservoir in one season had it not been for the truck proposition because we could not have worked 150 teams in and out. As it was, with the team making six trips a day from the hoist to the job we had to snap them all up the hill. We put on three teams and had four teams to bring up the three wagons. That was before we procured the trucks. Of course, the upkeep of trucks is heavy on that hill, but there is no question that the truck proposition was the life saver of the job.

There was one thing about the job that made it bad. It was started as a contract. Through the legal questions which arose it could not be awarded until the middle of the season of 1912, and that threw it late in the Fall before we could get any plant on the job, and the first season's work really did not amount to anything. Of course, the drainage was put in in the first season and that helped a lot. But we were up against the proposition this Spring of getting a concrete plant installed. We could not get that until we got the excavation all done. It was the 17th of June when we started to line the reservoir and we had 25 000 yards of concrete to pull through that mixer after the 17th of June. It is all in but about 1500 yards.

Mr. George H. Danforth: Going back to the trucks, after the season's work is over are they good for much?

Mr. S. L. Fuller: Oh yes. They are not for sale but I venture to say they have a value of about 50 percent their original cost. They cost $5000 and they are worth $2500 now. We do not believe in keeping machinery and as soon as we have the first service out of machinery we let somebody else get the second service. We find that more economical. But these trucks are not bad. If I remember right, to the first of September, the cost of repair parts that we had to put on was something like $15.00. Of course, there was a lot of repair parts furnished by the maker under the guaranty, but I do not think we spent $100 for repairs other than the general repairs you have to do. We have a night repair man and a day repair man and if anything goes wrong with the truck there is a man there.

Mr. H. H. Rankin: Did you figure on taking your material up the hill on an incline?

Mr. S. L. Fuller: I do not know, that was before I was on the job. It was contemplated by some of the bidders. Terminal facilities on an incline proposition would have been a difficult one to work out because the railroad is right on the bank of the river and you would have to cross the railroad tracks and the highway and the trolley track on a supported incline before you get to the hill, and then when you get up the hill you have to come down the other side. The water tank has an elevation of something like 80 ft. It is down the other side 100 ft. And the value of the incline after the job is over would be nothing, while the value of the trucks is material.

Mr. Elmer K. Hiles: What type of tire did you use?

Mr. S. L. Fuller: What they call a Goodrich wireless. Tires are a big expense on the truck, and we had to do a good bit on the roads. We had to agree to run between the street car tracks and where we ran off the street car tracks on the brick pavement—I do not know what the contract was—but the result is that we have to relay them.

A Member: What was the method used to get the proper support under the 60 ft. section that was undermined?

Mr. S. L. Fuller: The wall was not injured at all. We simply took out the stuff that had slipped, the line that was slipped was marked and retamped the embankment under there prior to putting the same toe pier in underneath. The slip did not do any damage at all but it gave us a little nervous prostration.

Mr. L. P. Blum: I would like to ask Mr. Lanpher what was the condition of the old steel pipe.

Mr. E. E. Lanpher: It was fine. There was practically no sediment or sand in the bottom of the pipes. It was in excellent shape, as good as I have ever seen and there was little evidence of rust. The mineral rubber coating was still in good condition after fourteen years in the ground.

Mr. L. P. Blum: How deep was it laid?

Mr. S. L. Fuller: About 4 ft. on the average. That same old pipe through Sharpsburg was very badly pitted on the outside.

I want to say on the subject of laying that waterproofing that it was a surprise to me. The only reason that we could dope out as to why that does not stick on the fairly dry concrete side as it does on the practically wet concrete is the dust that is on the concrete. Here is a piece of saturated burlap. I can crumple it all up and my hand is just as clean as it was before. The reason for that is that the saturated burlap has been treated with ash of some kind to keep it from sticking so you can unload it on rollers. Now there is some sort of dust that dries on the outside of the concrete, possibly, that prevents it from sticking as well.

Mr. Paul S. Whitman: I should like to inquire in reference to the steel plate pipe previously mentioned. What provision, if any, was made to prevent the steel from rusting? Was the pipe covered with a protective coating or was the surface of the steel simply scraped clean and then embedded in the concrete?

Mr. E. E. Lanpher: All steel pipe was covered with the same mixture, Pioneer Rubber Coating applied by a dipping process. Practically all steel pipe made in the Pittsburgh District is covered with that.

Mr. Paul S. Whitman: My reason for bringing this point to the attention of the meeting is due to the fact that there seems to be a marked diversity of opinion among engineers as to the proper protection for steel pipe lines and penstocks embedded in concrete. A recent instance brought to my attention was that of a pipe line recently fabricated by the firm with which I am connected for the City of Baltimore. The steel pipe in this case was 10 ft. in diameter and when erected was to have an inside coating of concrete 2½ in. thick and an outside coating of the same material 4 in. or more in thickness. The specifications called for sand blasting the steel before shipment from the fabricating shop and then applying an inside and outside coat of whitewash to protect the steel during transit from Pittsburgh to Baltimore. At the erection site the whitewash was to be removed by the use of wire brushes and the sand blasted surfaces of the steel were to come directly in contact with the encasing concrete. This was done to insure a firm bond between the steel and concrete which would not be possible if the steel were covered with a protective coating. The concrete covering itself is then relied upon to furnish sufficient protection to prevent the steel from rusting.

Mr. E. E. Lanpher: I think that possibly has some merit. Some day I am going to say that I believe in putting in cast iron pipe without coating, but for another reason entirely. Without doubt, the concrete will adhere better to a plain steel surface than to a painted surface but it will be practically impossible to coat the inside of a pipe by the dipping process without coating the outside. The steel pipe connections in the embankment only were covered with concrete; the objects of the concrete being to distribute the earth load and prevent leakage from following along the smooth pipe surface.

CONSTRUCTION DETAILS OF THE PANAMA CANAL LOCK GATES

By R. A. Pendergrass*

Before taking up this subject, it may be well to review some of the general features of the canal:

The length of the canal from deep water in the Atlantic to deep water in the Pacific is fifty miles. Leaving the Atlantic, a vessel will pass through an approach channel to the Gatun Locks; here it will be raised a distance of eighty-five feet to the level of Gatun Lake. This will be accomplished by a series of three locks. Through Gatun Lake it will proceed for a distance of twenty-five miles to the Culebra Cut. After passing through this cut a distance of nine miles to Pedro Miguel, it will be lowered thirty and one-third feet in one lockage to Lake Miraflores. The distance through this lake is about one and one-half miles. The vessel will then be lowered to the level of the Pacific Ocean in a series of two locks at Miraflores. It will then complete its passage through the canal by passing out through the channel into the Pacific Ocean. The time occupied by such a passage will be from ten to twelve hours.

From the foregoing, it will be seen that the locks are in three different groups, at Gatun, Pedro Miguel and Miraflores. All of these locks are double, corresponding to the two tracks of a double track railroad.

The lock chambers are 110 ft. wide, 1000 ft. long and of such a depth as to give a draught of 40 ft. As it was found when deciding upon the size of the lock chamber that over 95 percent of the vessels of the world were under 600 ft. in length, it was decided to subdivide each chamber by means of intermediate gates into lengths of 600 ft. and 400 ft. These intermedi-

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ate gates are 77 ft. high except at Pedro Miguel, where, on account of a greater lift they had to be made 79 ft. high.

At the lower end of each series of locks guard gates are provided for protecting the service gates just above. These gates open toward the lower level to hold back the water outside of the locks whenever it is found desirable to unwater the locks for repairs. These gates are 47 ft. 4 in. high except at the Pacific entrance where they had to be made 66 ft. high on account of a tidal variation of over 20 ft. The tidal variation at the Atlantic entrance is only 2 ft.

At the upper end of each series guard gates are also provided. These gates are 54 ft. 8 in. high. Other guard gates are also provided at the lower end of the higher level in each group.

The majority of the gates are 77 ft. high, but there are gates 47 ft. 4 in., 54 ft. 8 in., 66 ft., 77 ft., 77 ft. 10 in., 79 ft. and 82 ft. to satisfy varying conditions, only part of which have been outlined. The total number of gates is forty-six.

To protect the gates at the upper and lower approaches and at other points where the destruction of a gate might open up connections between two levels, fender chains have been provided.

At Gatun, Pedro Miguel and Miraflores above the upper locks there have been provided emergency dams to prevent the rush of water from the higher to a lower level in the event of any of the gates being damaged.

At first consideration was given to using rolling gates to protect the regular gates. After going into the design of such a gate, it was found that the weight of a single gate would be as much as two thousand tons. It was decided that this would be too expensive and that such a gate would be too unwieldy. It was then decided to make the guard gates as well as all others of the mitering type, and to protect them with fender chains as already mentioned.

A slope of two horizontal to one vertical was decided upon. This for a width of lock of 110 ft. made the length of each leaf 64 ft. The weight of one leaf varied from three hundred and ninety tons for a height of 47 ft. 4 in. to seven hundred

and thirty tons for a height of 82 ft. There were a total of ninety-two leaves, which together with the spare parts weighed sixty thousand tons.

It was decided to build up the gates of a succession of girders rather than to use an arched gate. It was considered that the latter type of gate would be more expensive to fabricate and that it would require thicker walls, thus again increasing the cost of the locks. It was also decided to sheath up both sides of the leaves, whereas in the design of smaller gates it has been customary to put sheathing on only one side of the leaf.

In the lower part of the leaf the girders are spaced 3 ft. 8 in. apart, in the middle section 4 ft. 2 in. and in the upper part 5 ft. apart.

The lower half of the leaf was made watertight to make the structure buoyant and thus relieve the bearing and anchorage. The upper half of each leaf was made watertight only on the downstream side, thus allowing this part of the leaf to fill up with water. Each leaf was divided up into compartments by means of vertical frames. In the lower part of the leaf or air chamber three sets of these frames were made watertight, thus giving four watertight compartments. Access was obtained to a compartment from the one next to it through manholes in the frames. In the watertight frames these manholes were covered by doors which could be opened from either side of the frame. There were also manholes through the horizontal girders but which were not covered with doors except at the top of the air chamber. The air chamber was made accessible from the top of the leaf, even though the upper part was filled with water, by means of a watertight manshaft. This manshaft had at the extreme top a watertight cover which prevented water getting down into the leaf when the top was sprayed by waves.

The gates when closed with the water pressure on the upstream side, act as three hinged arches. The thrust at the hinges instead of being concentrated at the girders is made continuous by means of a series of short vertical girders, or diaphragms "*A*" as they have been called throughout the design and construction. These diaphragms frame into the main

girders and are braced by means of another set of diaphragms "*B*" connected to the horizontal girders and sheathing plates. Diaphragms "*A*" transfer the thrust to end reaction castings. These castings have wings connecting to both sides of the leaf. The end reaction castings transmit the thrust in turn to nickel steel bearing plates, on each of which one face is turned to a radius of 10½ in. The flat face of these bearing plates are tapped for bolts which go through the head of the end reaction castings. These bolts are for the purpose of adjusting the bearing plates to obtain a perfectly vertical line of contact. After the bearing plates are adjusted to their final position, the small space between them and the end reaction castings is filled with babbitt metal. At the center of the gate, the bearing plates on the miter ends of the two leaves come together. At the quoin end the bearing plates come in contact with another bearing plate having a concave surface bored to a 12 in. radius and attached to castings built into the masonry.

The weight of the gate when the lock is empty is entirely supported at the quoin end of the leaf. This is not in accordance with European practice. For the largest gates built in Europe, rollers have been provided under the miter end which roll on a track built into the bottom of the lock chamber. To transfer the entire weight of the leaf to the masonry, a large steel heel casting is built into the bottom panel of the leaf at the quoin end. This serves to collect the weight of the gate and to transfer it to a smaller casting made of vanadium steel and connected to the lower side of the bottom girder. This casting is called the "upper pintle casting". In it is fastened a manganese bronze bushing, which in turn fits over a hemispherical nickel steel pintle. This pintle in turn is supported by a casting built into the masonry.

As has been mentioned, the entire weight of the leaf is supported at one end, thus involving a cantilever action. To prevent overturning, the upper end of the leaf is held by means of a vanadium steel yoke casting connecting to a casting built into the masonry and fastened to the anchorage. This casting has two jaws to connect to the different parts of the anchor-

Fig. 1. Upper Level at Gatun, looking North.


Fig. 2 View showing Skeleton of Gate.


Fig. 3. View showing Completed Gate.

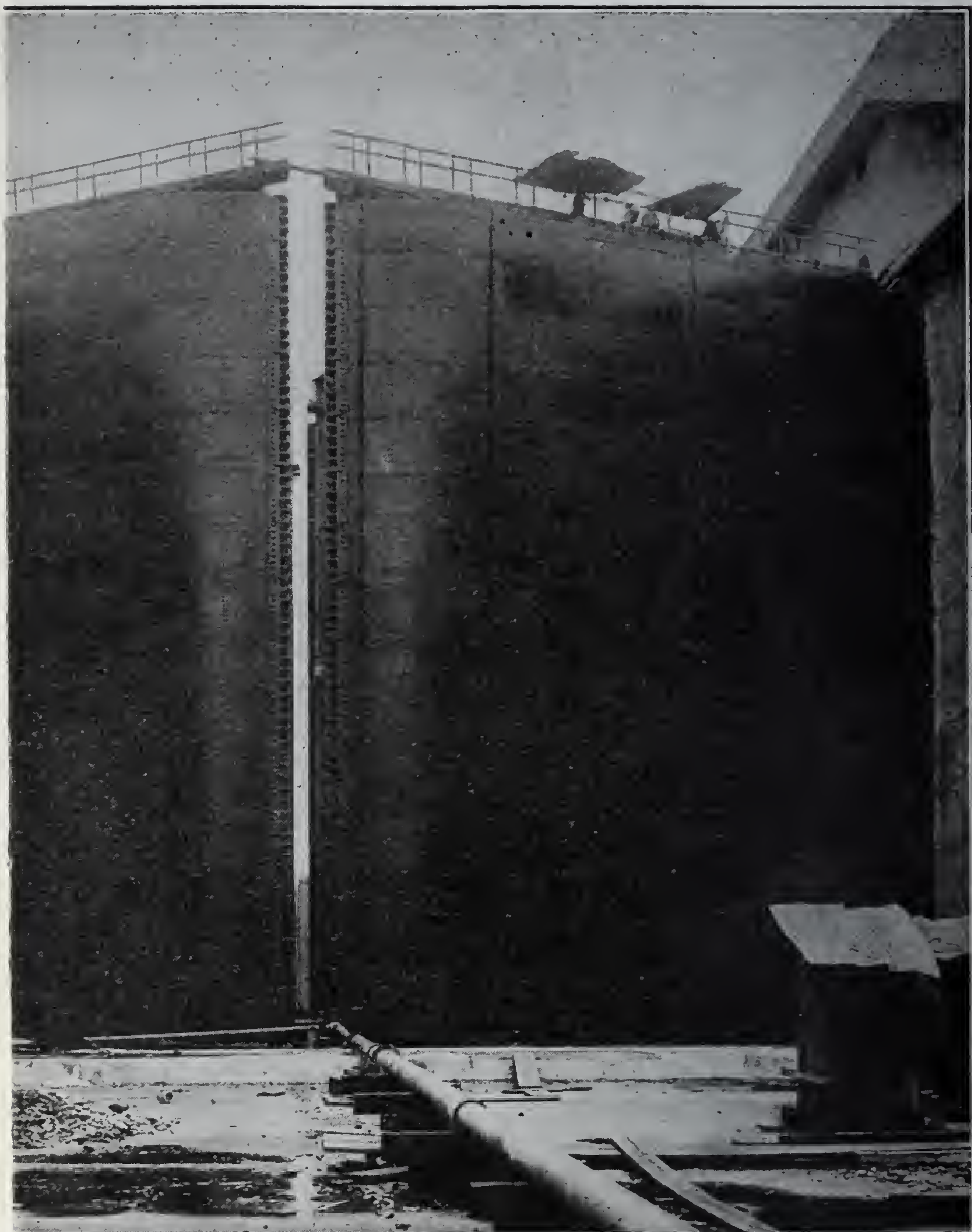


Fig. 3. View showing Completed Gate.

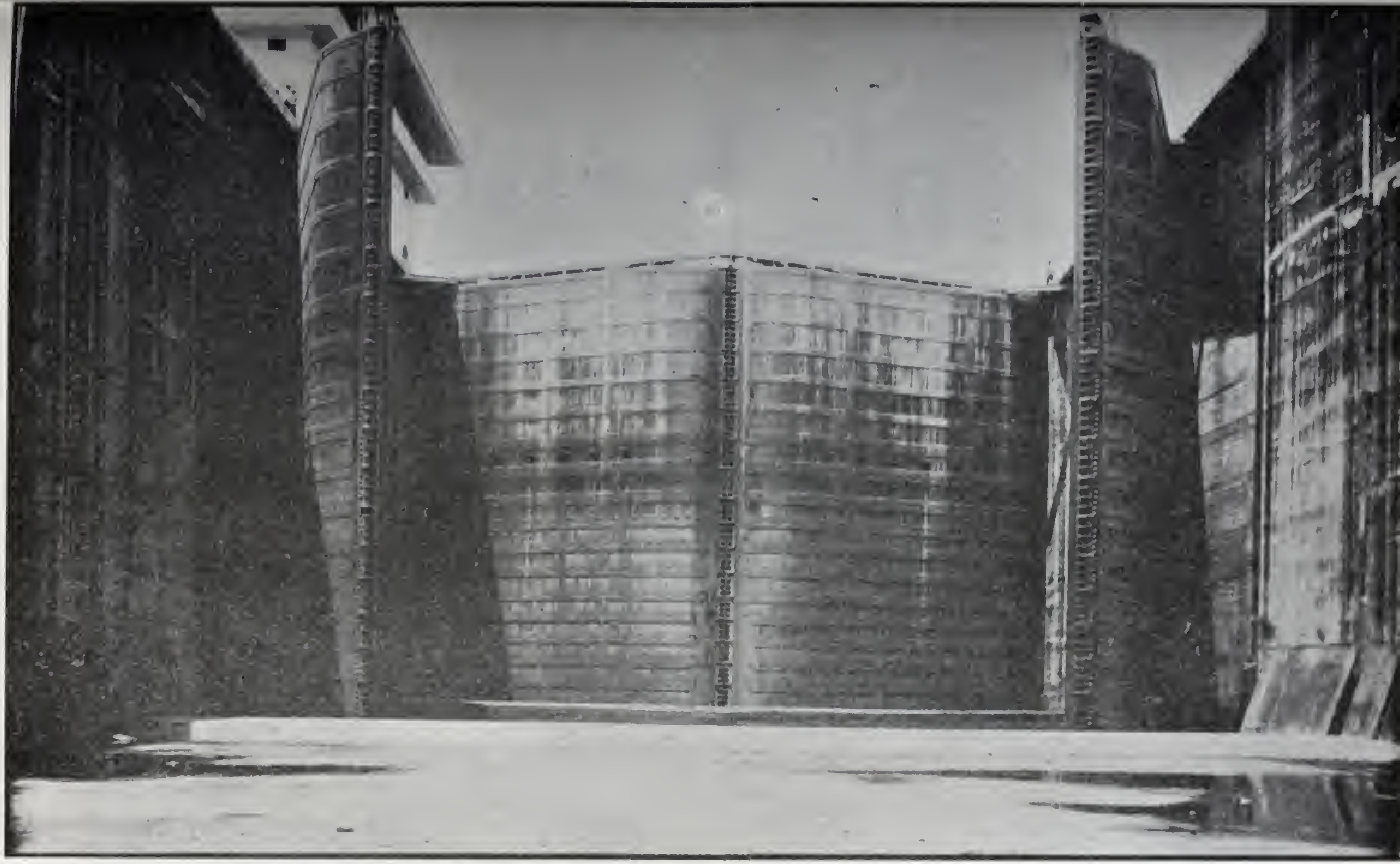


Fig. 4. Upstream View of 77 ft. Guard and Service Gates.

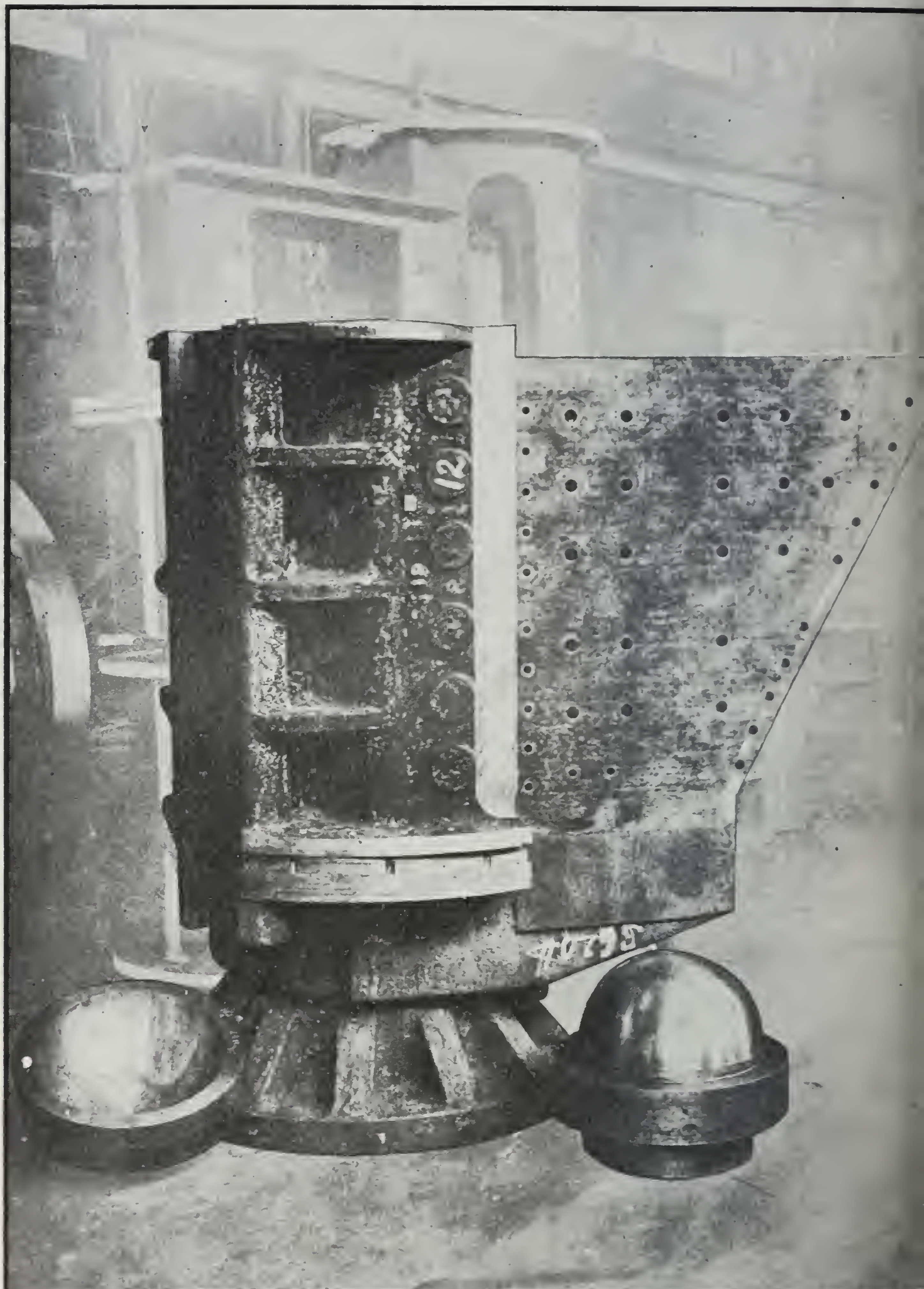


Fig. 5. Assembly of Castings at Pintle Bearing.

age. The specifications required that two of these yokes be tested to destruction or to the capacity of the largest testing machine in the United States. Arrangements were therefore made for making this test on the eye-bar testing machine at Ambridge. In this test, while it was found possible to rupture the smaller jaw, yet, although a load of 3 625 000 lb. was applied, it was found impossible to rupture the larger jaw. This yoke casting projects between the upper girder of the leaf and a structural steel yoke, a nickel steel pin 10 in. in diameter passing through holes bored in the yoke, yoke casting and upper girder; the hole in the yoke casting being fitted with a manganese bronze bushing.

As has been pointed out, both sides of the leaf are covered with sheathing plates, which vary in thickness from 7-16 in. at the top to 1 inch at the bottom of the largest leaf. This sheathing is stiffened at intervals by channel or angle intercostals. The sheathing or skin plates have horizontal splices at each girder. The splice plates covering these joints also serve as cover plates for the girders. The sheathing plates do not extend quite to the ends of the girders, but butt against a bent plate running vertically, which ties the sides and ends of the leaf together. The bent plates on the two sides are spliced by a vertical end plate. The bent plates are spliced to the sheathing plates by doubling plates. These plates are extremely large at the most vital parts of the leaf, viz: the yoke and heel connections.

The leaves are opened and closed by means of a strut connected to the top girder. This strut is attached at the other end to a gear 19 ft. in diameter. This gear is operated through a train of smaller gears by means of a 50 h. p. motor at 500 r. p. m. The total gear reduction is in the ratio of 1800 to 1, and the time of operation is two minutes.

On the top girder of each leaf at the miter end is placed a miter forcing mechanism. This is to bring the two leaves together when slightly separated or warped by temperature changes. This mechanism also serves to keep the two leaves locked together against wave action.

When the lock chambers are full of water, the upper half

of the gate is also filled. To allow the water to flow out of the gate when the water level is lowered, holes are cut in the upstream sheathing plates in the panel just above the air chamber. Scuppers are also provided to drain out the water standing on top of the air chamber girder and below the bottom of the holes in sheathing plates. These scuppers are in the form of elbows, connecting to the web of girder at top of air chamber and extending through the sheathing in the panel just below.

Fig. 6. Upstream View of Partly Opened Gate.

The upstream sheathing plates are extended about 3 ft. above the top girder. This serves to support the curb on one side of a footwalk 2 ft. 4 in. wide. This walk is supported by frames resting on the top girder. On the lower guard gates the walk is made much wider and rails are provided with a 5 ft. gauge and curved at the center so that cars can be run across these gates. The walks are protected on each side by gas pipe railing. To avoid interference with towing ropes, the railing is made collapsible and is operated by a 7 h. p. motor turning a screw on which two bronze cross heads travel. The travel of these cross heads brings levers into action which revolves the railing posts into a horizontal position. which is made possible by the tee at the top of the post being pin connected to the post. The gas pipe used in the center section of the rail is made smaller in diameter so that it will telescope into the other rails.

As some water might leak into the air chamber, provision was made to pump this out. Suction pipes extend from a centrifugal pump in the center to each compartment. This pump is operated by a 7½ h. p. motor placed in the top compartment of the air chamber. A float is placed in the bottom compartment and is connected by means of a chain running up through a pipe to a float switch on top of the leaf.

At the bottom of the downstream side of each leaf is fixed a wooden sill. This sill is of greenheart timber which was secured in Demerara, South America. This timber is so hard that it is free from the attacks of teredo and other wood boring parasites. Its specific gravity is so great that it will not float in water. This timber is quite difficult to work but is liable to crack if exposed to the sun. To avoid this it should be submerged in water or painted with a preparation called "Lorac". When the gate is closed, this timber bears against a similar timber attached to a casting in the floor of the lock chamber.

At the top of the leaf on the downstream side is attached a greenheart fender to protect the steelwork from the rubbing of vessels.

The unusual feature of this work from a bridge shop point

of view, is that a large amount of the construction must be watertight and that the work must be fabricated with such a degree of accuracy, that, when erected, very little water will come through at the bearing points. The specifications call for all rivets in watertight work to have pan heads. On account of the enormous number of rivets, there being a total of 5 750 000 field rivets, it was deemed advisable to investigate the practice of plants building pipes, tanks, boilers and ships. It was found to be the practice in building pipes, tanks and boilers to use cone head rivets, particularly for watertight structures. For gas tight structures countersunk rivets were frequently used. On ship work it was found to be the general practice to use countersunk heads not only for outside work but also for the interior work, such as bulkheads. This head is not made flush with the surface of the steel but has a slight curved projection. The angle of countersink is somewhat different from that ordinarily used by a bridge shop and the depth of countersink is considerably greater. This refers particularly to the United States Naval Standard, which was followed for all countersunk rivets in this work. It was finally decided to use a countersunk head for all watertight rivets in the legs of angles on watertight frames and girders where it would be difficult if not impossible to caulk around the entire head. For all other rivets where the rivet head was easily accessible, pan head rivets were used. As the specifications required that all holes be punched small and reamed in the field after assembling, all field holes where countersunk heads were to be used had to be countersunk in the field. To save this expense, the erector obtained permission to use pan head instead of countersunk head rivets for those rivets connecting watertight frames to sheathing. It was soon found that this resulted in a considerable number of leaky rivets so that this was abandoned.

As has been mentioned, the air chamber was subdivided into four compartments by watertight frames. The angles of these frames were caulked against the girders and sheathing plates. The flange angles of the girders except those at top and bottom of air chamber were however not caulked against the webs. This would permit water to pass from one compart-

ment to another by going between the web and flange angles. To prevent this, water stops were placed between the flange angles and webs at all watertight frame connections. These water stops were made of No. 10 cotton duck canvas soaked with red lead and linseed oil. Similar water stops were used in a great many other places where caulking would be impossible. They were used under channels and angles where it would have been necessary to caulk the heels of these, as this was considered undesirable. They were used under pieces which had to be bolted, such as the bottom fender angles. They were also used as an extra precaution in some places, as under the end reaction castings and heel castings.

A considerable number of bolts were used, particularly in attaching the castings to the gates, and practically all of these had to be made watertight. This result was accomplished by using grummets under the heads or nuts of the bolts. These grummets were made of hemp fiber in the form of a washer and soaked in red lead and linseed oil. To prevent the grummet from being destroyed when the nut was screwed up, a thin washer $\frac{1}{8}$ in. or $\frac{3}{16}$ in. thick was placed between the nut and the grummet.

As there were several hundred thousand feet of metal which had to be caulked, the question of whether such edges should be beveled for caulking was investigated. It was found that boiler and tank works generally sheared such edges on a bevel. This was done apparently to obtain a sharp caulking edge. As the specifications for this work required that all sheared edges be planed, it would have been necessary, to follow this practice, to plane all such edges on a bevel. It was decided that this was not necessary and that if the edges were planed at right angles to the surface of the plate a sufficiently sharp edge would be obtained for caulking. There were therefore no beveled edges used in this entire work except for a small amount of material which was less than $\frac{3}{8}$ in. in thickness. Where the edges of universal mill plates had to be caulked, these edges were planed for this purpose.

At the intersection of vertical and horizontal splices on the skin a joint was made which had to be watertight. At first

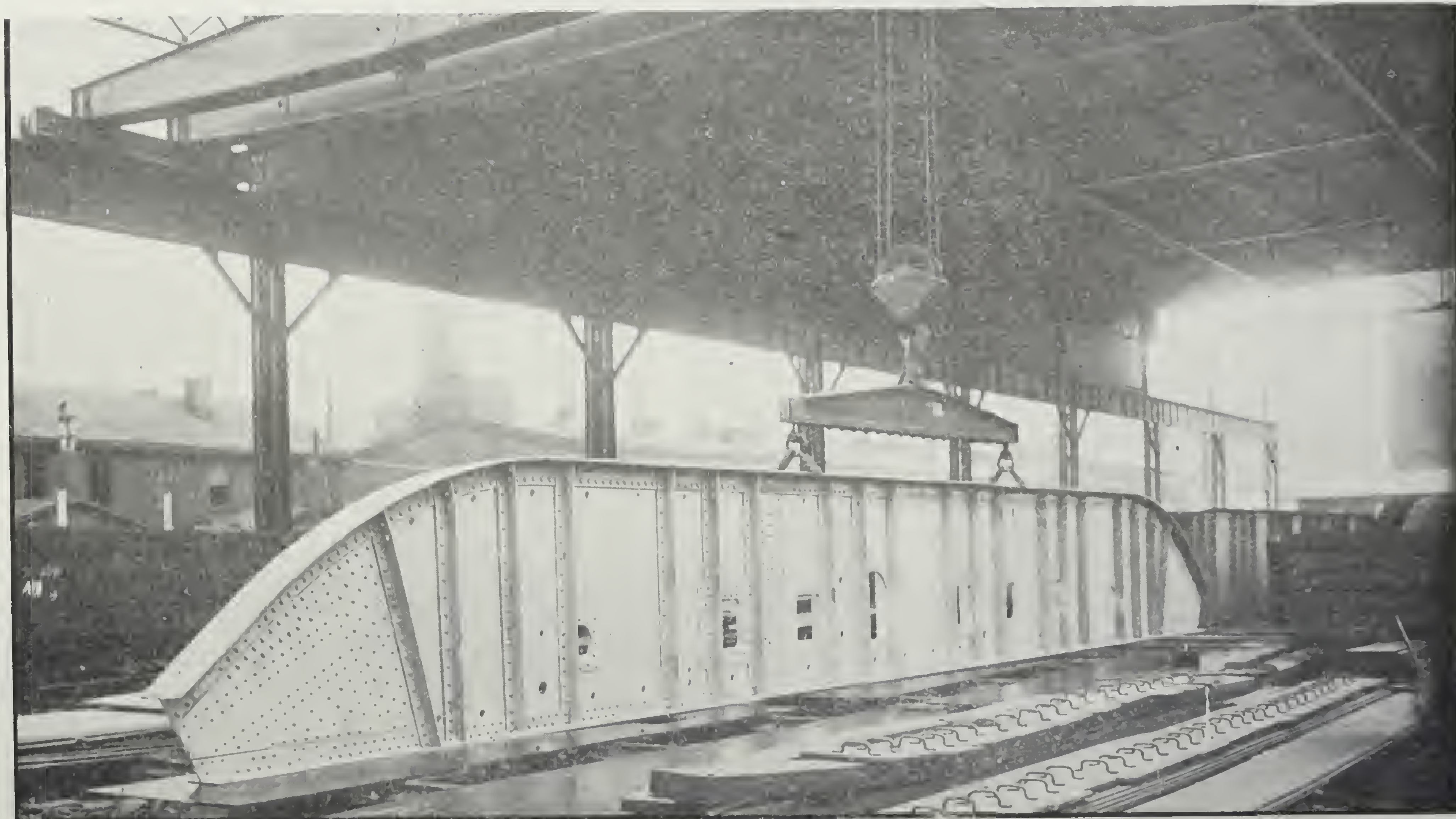


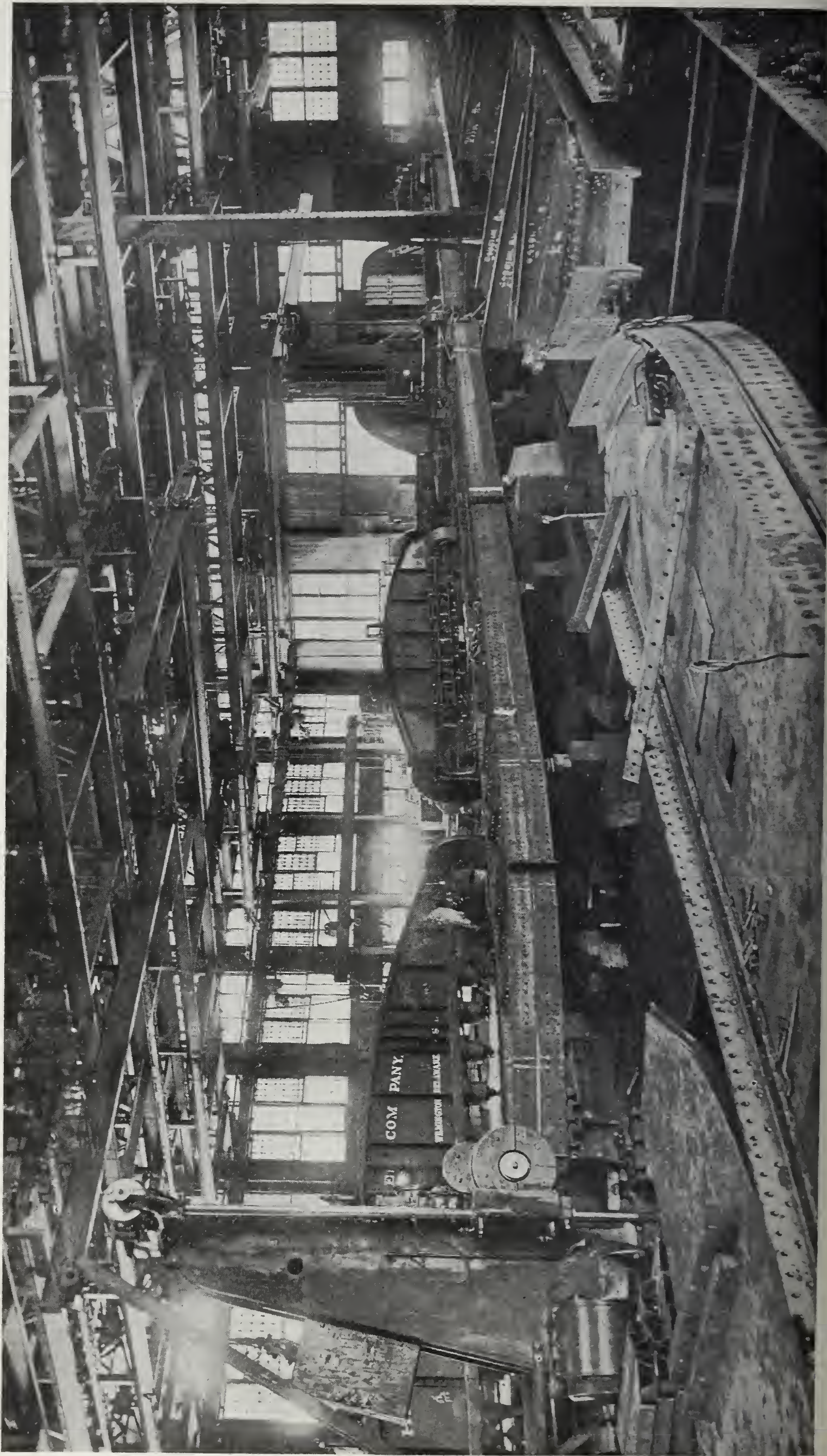
Fig. 7. Water Chamber Girder, completed ready for shipment.

consideration was given to scarfing the vertical plates to a knife edge, inserting this edge in under the horizontal plate as is generally done in tank work. This practice however was not adopted. The ends of the vertical plates were milled with only 1-32 in. clearance and butt caulked against the horizontal plates.

The watertight frames had a bounding angle which was caulked against girders, sheathing plates and webs of frames. This angle was designed with four joints which were to be butt caulked. This was tried but did not prove satisfactory. Electric welding was also tried but abandoned. Dishing the webs of the frames to form flanges was also investigated but was considered too expensive. It was then decided to forge these angles by hand as is done on similar angles used in building ships, and anglesmiths were secured from some of the ship building plants to do this work. The angles to be forged were cut long enough to go entirely around the frame. These angles were then crimped in four places to fit over the flange angles of the girders. *V*-shaped pieces were then cut out at four points so that when the angle was bent into a rectangular outline there would be no excess of metal at the corners. These corners were then welded, making one continuous frame. The accuracy obtained by these anglesmiths in making these frames is marvelous to one not familiar with this kind of work.

The horizontal girders are 7 ft. deep. This depth had to be reduced at the ends to accommodate the end bearings. This was accomplished by curving the upstream side of the girders for a short distance to a radius of 15 ft., sloping from the end of the curve to the end of the girder. The flange angles on this side of the girder were punched in an angle multiple punch before bending. These angles were afterwards bent without heating in a large bulldozer. A few angles were spoiled before the correct allowance in the spacing of the holes was determined to offset the effect of stretching in bending. This however was a small matter compared with the saving brought about by punching four angles at a time instead of laying off and punching one hole at a time, which would have been necessary if the angles had been bent before being punched.

The bent plates at the ends had to be made with a great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degree of accuracy to meet with the approval of the Engineer in charge. These plates were heated and bent in the bulldozer at first, but as satisfactory results could not be obtained, arrangements were made to have them bent at Homestead in the armor plate department of the Carnegie Steel Co.

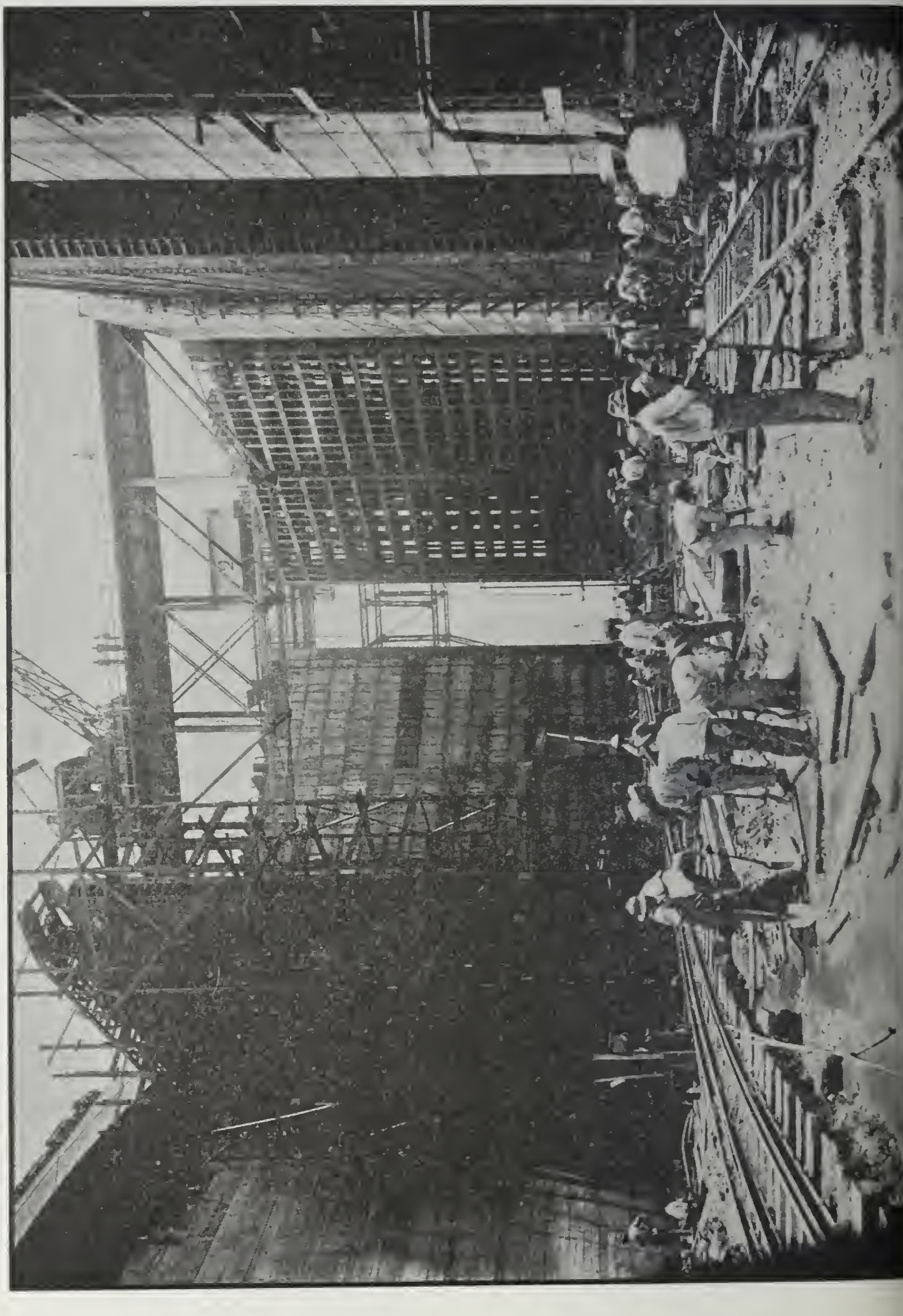
The ends of the girders had to be made with great accuracy to fit properly to the end reaction castings. To accomplish this, cast steel frames were made to conform to the outline of the girder. These frames were used in fitting, and were kept in place until the girder was entirely riveted.

It was also important that all girders be made of exactly the same length. To secure this result, a pair of milling machines was purchased and set carefully to the correct angle and placed at exactly the right distance apart. These machines were left in position until after all girders on the entire work were milled and were not used for any other work.

The upstream sheathing and cover plates had to be bent to conform to the outline of the girders. The sheathing plates were bent in the shop in a bending roll. The cover plates however were bent in the field as erected.

As a great many of the leaves had as many as eighteen stories and as the two leaves in one gate should be of practically the same height on account of the miter forcing mechanism, the matter of packing up of the various members was considered. It was decided to make the watertight frames 1-16 in. less and the non-watertight frames and diaphragms "*A*" and "*B*" 3-32 in. less than the theoretical lengths. In addition to this, the reaction castings and frames except watertight ones were made ¼ in. short in every fourth panel and fillers of various thicknesses were provided. The wisdom of this was demonstrated when the leaves were erected, as the thickness and number of fillers used varied considerably in different leaves.

The mill scale was removed from all material either by sand blasting or pickling. In general, all shop riveted work was sand blasted, and all punched work, such as sheathing plates, cover plates, doubling plates and splice plates were pickled. Before building the pickling plant an investigation was made of the practice of a considerable number of companies



having such plants. Because such a diversity of practice was found, it was decided to make an investigation to determine the following points:

First: The influence of time on the removal of scale and rust.

Second: The effect of temperature.

Third: The influence of the strength of the solution.

Fourth: The action of the solution on good metal.

Fifth: The comparative results to be obtained by the use of hydrochloric and sulphuric acids.

Two hundred and sixteen pieces of plate $4 \times 8 \times \frac{7}{16}$ in. in thickness, each weighing about 4 lb. were used. One-half of these were cut from plates badly rusted, the other half of plates fresh from the mill. One-third of all the specimens used were sand blasted, on the assumption that the action of the solution on these would be a measure of the action of the acid on the good metal. All the pieces were stamped with marks for the purpose of identification and were weighed on balance scales with agate bearings and accurate to 0.01 ounce. The weight and condition of each piece was carefully observed and recorded. The plates were immersed in solution of 1 to 15, 1 to 25 and 1 to 35, the ratios given being by volume. The periods of immersion were, for hydrochloric acid: two, six, ten and fourteen hours; and for sulphuric acid: one, two, three and six hours. The temperature of the solution varied from 50 to 110 deg. Fahr. The hydrochloric acid was what is known as 20 degrees commercial and sulphuric as 66 degrees commercial. After removal from the bath the specimens were washed in lime water and then all loose material was removed by rubbing with waste. The plates were then allowed to dry and then weighed.

The deductions made from these experiments were as follows:

First: For the rapid removal of scale, sulphuric acid is to be preferred.

Second: The rate of removal of scale and rust is a direct function of the temperature, and for quick action the solution should be heated.

Third: The rate of removal of scale and rust increases with

the strength of the solution, but for sulphuric acid is not directly proportional to the strength. For hydrochloric acid there seems to be no advantage in using a stronger solution than 1 to 25.

Fourth: The action of a hydrochloric acid solution on good metal practically stops after six hours, but with a solution of sulphuric acid this action is continuous and the loss of metal nearly proportional to the time of immersion.

In general, the amount of weight removed in sand blasting was more than that removed in pickling. The amount of weight removed from the sand blasted specimens in pickling varied from 10 to 20 percent of that removed from the specimens not sand blasted. The greatest percentage of loss in sand blasting was 1 1-3 percent, in pickling of sand blasted specimens ¼ percent and of the unsand blasted specimens 1 percent.

Manholes were cut in the watertight frames in the air chamber to admit passing from one compartment to another. This required manhole frames and covers to prevent the passage of water between the compartments. These covers could be opened from either side of the frame by means of levers, one on each side of the frame. To make the covers watertight a 1¼ × ⅜ in. rubber gasket was specified to be placed between the contact surfaces of cover and frame. It was soon found that the pressure produced on the gasket by means of the lever working in the hasp was insufficient to prevent leaks. The first step taken to obviate this difficulty was to reduce the width of the gasket to ¾ in. so as to increase the intensity of pressure. This improved conditions, but the leakage was still considerable. Various types of gaskets were then tried. Some of these had a single wire core, others several small wire cores. The one found to give the best result had a spiral fiber insert and the top of the gasket was beveled from the center to the sides, thus greatly increasing the unit pressure. This proved quite satisfactory until a water pressure on the cover of 35 to 40 lb. per square inch was reached when the gasket would blow out. To overcome this a groove was cut in the cover into which the gasket was inserted.

Some of the lower guard gates were erected by locomotive cranes working from tracks in the bottom of the lock chamber.

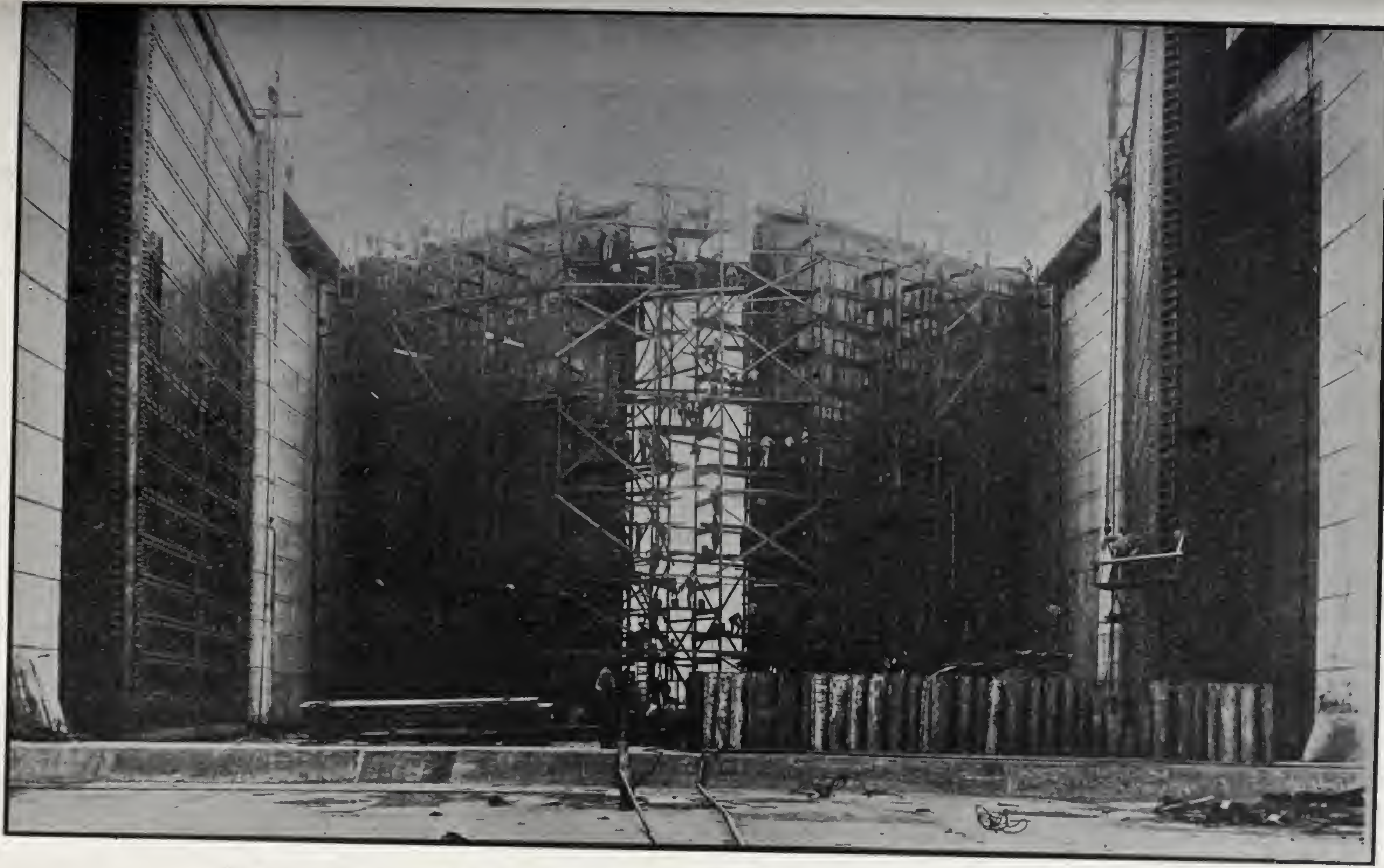


Fig. 10. Upstream View showing Completed Gate and one in course of erection.

Most of the gates however were erected from the top by locomotive cranes running out on to specially designed erection bridges spanning the lock chamber. These bridges had a span of 115 ft. made necessary by the clear width of chamber of 110 ft. After the complete erection of a gate, the bridge was moved to the next gate by running it along rails on the walls. At each lock gate recesses were provided in the wall so that the gates when open would swing back into these recesses, leaving the full

Fig. 11. Upstream View of Guard Gate.

width of chamber. These recesses had a cover, but as this was not considered strong enough to support the weight of the bridge in moving, extensions were provided to increase the span of the bridge sufficient to reach beyond the recess.

The largest cranes used were fifty tons capacity. The heaviest pieces lifted were the girders, which weighed eighteen tons each and which had to be swung into position with a reach of from 20 to 25 ft. This produced a very heavy load on the truss next to the gate and a comparatively small load on the outside truss. To partly equalize this load on the two trusses, very heavy bracing was used between them.

The leaves could not be erected in their final position on the pintle bearings, as there would not have been sufficient space between the masonry and the steel to allow the work on the ends to be performed. They were therefore erected about 5 ft. out from their final position and in a partly open position so as to allow room for working around the miter ends. They were placed on a grillage of *I*-beams which had been set perfectly true to level and grouted. This raised the leaves above their final elevation, which was necessary to give access to the underside of the bottom girder for riveting and caulking and also that the leaves might be moved back and lowered on to the pintle previously placed. The bottom girder was fitted with the upper pintle and heel casting and then laid on the grillage beams. The skeleton consisting of girders, diaphragms "*A*" and "*B*", watertight and non-watertight frames and intercostals was then erected to the full height. In this work, an engineer's level and transit were constantly used to keep the steel-work absolutely level and plumb. To make this possible, different thicknesses of fillers were used at adjustment points which occurred at every fourth panel. In plumbing the leaves, steel cable guys with steamboat ratchets were used. In this operation, 40 lb. plumb bobs suspended in oil by a piano wire were put in position and allowed to remain until the gate was entirely finished.

When the skeleton was in perfect alignment the connections of the various diaphragms and intercostals to the girders were riveted. This was then followed by the erection of the covering, consisting of sheathing, cover plates, doubling

plates, splice plates, etc. As all the holes in these were punched small in the shop, the next operation was the reaming of the holes. For this purpose special electric two spindle reamers as well as ordinary hand reamers were used. These were operated from scaffolds either hung from the top of the leaf or fastened to the side. After the reaming, the next operation was riveting, followed by caulking. The tools for this purpose were operated by compressed air.

The next operation was preparing the end plates of the leaf for the erection of the end reaction castings. As nothing short of perfection was satisfactory, it required a great amount of grinding to get these surfaces absolutely smooth and to a true vertical line. After this, the end reaction castings were placed in position with a water stop between them and the steelwork. The castings were adjusted laterally by means of wedges and various thicknesses of fillers between them and the doubling plates. When this was done, the castings were then riveted to the leaf. The nickel steel bearing plates were then erected. They were plumbed and babbitted on both the quoin ends of leaves forming one gate. These bearings were however babbitted at only one of the two miter ends in a gate. The next step was to attach a pair of "*A*" frames to each side of a leaf. These "*A*" frames were supported on adjustable wedge devices such as have been used to obtain the proper camber in the erection of large truss bridges. These wedges rest on nests of rollers. The leaf was then jacked back into position and lowered by means of the wedges on to the pintle. The yoke at the top was connected and the leaf finally swung.

The specifications required that the entire air chamber, the frames subdividing it into compartments and the downstream sheathing above the air chamber be made watertight and that as a preliminary test of this watertightness that the gate be subjected to the impact from a fire stream from a hose 2 in. in diameter with a smooth 1-inch nozzle with a pressure at the nozzle of at least 80 lb. per sq. in. It was pointed out that this method of testing would prove unsatisfactory, as this stream would be applied from the outside or caulked side of the structure and that if any leaks developed, it would be very

Fig. 12. General View at Pedro Miguel showing Erection Bridges.

Fig. 13. Upper Level at Gatun looking South toward Gatun Lake.

uncertain where the leak actually occurred, as the water might seep out on the inside at a considerable distance from the leak.

The method finally adopted was to fill up the entire air chamber and manshaft with water. If any leaks developed, the water would then show at the point where the leak actually occurred and this joint could be then readily caulked. This was a very severe test, as the pressure was against the caulking.

To test the watertight frames, one compartment at a time was emptied and an inspection of the frames made from the empty compartment.

In visiting the ship building plants it was found that when a ship was first tested for watertightness numerous leaks developed. Many of these leaks were stopped by caulking, but some seemed to defy all ordinary methods. When such a leak occurred, a hole was tapped through the outer plate at the leak and into this was screwed what is known as a red lead gun. This gun consisted of a cylinder, into the lower end of which was fitted a pipe for screwing into the tapped hole in the vessel. In this cylinder was a piston head, the piston rod extending through the upper end of the cylinder. The cap of the cylinder was tapped and the piston rod threaded. On the end of the rod was a hand wheel. The cylinder was filled with a red lead paste, so that by turning the wheel this paste was injected into the joints under considerable pressure. Such treatment usually stopped the leaks. The writer saw such guns having a cylinder 6 in. in diameter and 5 ft. long. Some of these guns were provided for use on the Isthmus, although not as large as the ones to which reference has been made, but they were never found necessary and were therefore never used.

After the water test was concluded, the final adjustment of the bearing plates at the miter end was made with the gate closed. As has been mentioned, only one of the two miter bearings in the gate had been babbitted. The other bearing plate was now adjusted. This was adjusted approximately to the desired position in the day time, but the final adjustment was made at midnight when there would be no disturbing effect from the sun rays. The temperature inside of the leaf at this time was generally about eighty-two degrees. This bearing

plate was set to an opening of 0.003 in. at the top and 0.024 in. at the bottom, this being done to offset the effect of the greater water pressure at the bottom. After the final adjustment had been made, concrete was placed in the bottom panel to form a sump required in connection with the pumping system, which was then installed.

After the operating strut and mitering mechanism had been installed by the Commission, the footwalk was put in place and the handrailing erected. The leaf was not yet complete, as the painting yet remained to be done. This was a big undertaking in itself, as the entire interior was coated with bitumastic enamel applied hot. To make it possible for men to work in the interior in applying this hot enamel, a ventilating system was provided.

After a gate was entirely completed, the final test was made by filling the lock chamber with water up to the top of the gate. The results obtained in this test were quite remarkable, as absolutely no leaks developed through the gate, although they were subjected in some cases to a head of 80 ft. The end bearings were lined up so perfectly that no water at all got through at these bearings. The only water which got through in any place was at the bottom sill. One of the erectors on the work made the statement that "One man could drink all the water coming through one gate." Although a very careful study of the details had been made and every precaution taken to insure the watertightness of these structures, all those connected with this work were very much interested to get a report of the test of the first gate and it is needless to say that considerable satisfaction was felt when these reports came in.

Another indication of the accuracy of the work was, that a single workman with a crow-bar could revolve any leaf and that in one case the leaf could be turned by one man without the use of a crow-bar.

DISCUSSION.

Mr. Samuel E. Duff*: The author is to be congratulated for his success in bringing out within the limits of one paper, a comprehensive and clear description of the essential

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facts in regard to the design and construction of the Panama Canal Lock Gates. He has clearly shown the ruling reason for the adoption of miter gates throughout, rather than the adoption of the principle of rolling or floating for the movement of the guard gates; namely, the very great reduction in cost thereby. No doubt this matter was very thoroughly investigated by the Engineers of the Canal Commission, and it would be most interesting to study the details of their findings. It would have been more interesting to study a comparison of actual contract tenders for the gates under the two designs. The reduction in the amount of duplicate work as well as the probable complications and delays incident to the erection of the rolling gate, as against the design adopted, would be very interesting if expressed in money values as calculated by contractors making tenders.

The adoption of the miter gate design afforded great possibilities for duplication of parts, and this was taken advantage of to the greatest possible extent by the Engineers of the Commission. The author has not brought out as strongly as he might have done this phase of the adopted design. The use of such a great number of parts exactly the same in all respects, served very materially to decrease the cost as figured by all contractors making tenders. The contractors who actually carried out the work were able to take probably greater advantage of this feature of the design than would have been done by any other fabricating concern capable of carrying out the work. The result of the careful study of the design by the Canal Commission with the specific object of procuring uniformity of design and greatest possible proportion of exactly similar parts throughout the work, together with the advanced facilities of the contractors and the initiative shown by their organization in extending their already unique fabricating methods to the highest efficiency, resulted in a cost to the Government for these lock gates far less than anyone would have believed possible before the contract was placed. As a final word touching the general design, it is certainly remarkable that the Engineers of the Commission were able to make a design so highly efficient as regards fabrication and erection that practically no changes

were made during the construction. It seems to me that this is one of the greatest lessons to be learned from an examination of this very important work.

Referring to the details of the design the author might have brought out more clearly the fact that the girder spacing and other details of all gates are exactly the same from the top of the gate towards the bottom, so that the only difference between the high gates and the low ones is found in the addition of construction at the bottom, so uniform in design as to produce the greatest possible number of additional duplicate parts. The great care shown in working out the design of the mitering surfaces so as to permit them to be accurately and permanently adjusted is notable. The same thing may be said of the design of the quoins. It will be very interesting to note as time goes by, whether or not the use of the gates will render inefficient the seal procured at the quoins by the design shown.

It is to be regretted that the author has not more completely shown the details of the miter closing mechanism as well as the operating machinery for the gates. We understand of course, that these parts were not included in the contract over which the author had supervision. I hope the Society may have the benefit of a full description of the design, construction and operation of these parts from some member who is familiar with them.

It would also be very interesting to know what provision, if any, was made by the designing engineers for deflection of the gate leaves due to their own weight when the locks were empty. The elasticity of the material combined with the great weight would certainly cause an appreciable difference in the elevation of the miter end of the gate, between a condition of support entirely by pintle and top pin, and a condition of partial support of the gate by the air chambers; and again when gates were closed and weight of water was acting on the top of the gate. It is probable of course that the different leaves would act uniformly and thereby maintain constant relations between the leaves of one pair, but it would be interesting to know what calculations, if any, were made on this point, and how the results checked with the calculations. It would also be interesting

to know whether or not any provision was made for compression of the leaves under the thrust of the water when lock was full, and if so, how these calculations checked with the actual results. This would likely affect the adjustment of the greenheart sills.

In discussing the fabrication of the gates the author deals mostly with those matters which undoubtedly gave the contractors most concern for the reason that the conditions were different from what their usual line of work produces; namely, the necessity of water tight work at many points. Candid statements of the author as to the difficulties of calking, obtaining water tight bulk head flanges, etc., including the use of canvas water stops and grummets, indicate the worry suffered by structural contractors when they encounter such work. The results obtained were doubtless good considering the circumstances.

It seems to me, however, that the author, due no doubt to modesty, but possibly also to the fact that it does not seem unusual to him, has not brought out clearly the fact that the small amount of trouble encountered is undoubtedly due to the accuracy with which the fabrication of the separate parts was carried out. Engineers should take particular note of the fact that accuracy in fabrication is a more common attribute of what is known as structural and bridge work than of ship building, or other types of work which can be compared to these lock gates. In my opinion the Commission were very fortunate in having placed this contract with the McClintic-Marshall Construction Company for the reason that they have developed to the highest degree the art of accurate punching, and the duplication of exact punching on different pieces of material. This is an old story to the author and for that reason probably does not appear to be of so great importance as it should be shown to be for the proper information of all engineers who examine this subject.

I did not see any of the fabricating work done, but I strongly suspect that practically all of the material entering into these gates passed through spacing punches which produce absolute accuracy. I believe this to be true for the reason that

the contractors have the best equipment of this kind, as far as I know, in the world, and the design of these gates permitted the use of the spacing punches to a high degree. I am sure the members of the Society would be greatly instructed by a full description of the methods and results obtained by spacing punches as against the more common method of laying off from templets and punching one hole at a time.

The author refers to this matter in connection with the curved angles on the down stream sides of the horizontal girders, mentioning the difficulty of so fixing the spacing that the angles would be true to length after bending, but I wish he would give you some indication of the enormous saving in labor and expense brought about by the use of spacing punches on this lock gate work. It would, perhaps, be unfair to ask him to indicate the cost in terms of dollars per ton for the punching, but he should at least give you an idea of the comparative number of holes which can be punched by this method in an hour, or a day, as against the single hole method. Great credit should be given the contractors for their care and accuracy in all the operations involved, and it is interesting to learn of the care taken to provide for packing of a large number of pieces close together by making them short and producing the proper total length with the minimum of adjustment, but in my opinion the most important matter is the accurate punching of all parts of the structure to a uniform standard of measurement. This more than any one other thing made possible the accuracy in general dimensions of the structure and the proper fitting of the various parts. I repeat that I believe the author and the contractors owe it to themselves and to the Society to describe their punching methods in general terms at least.

In regard to the riveting to produce water tight work it is not clear just what the author means by a pan-head rivet. It would be interesting to learn the exact dimensions of this head as well as the dimensions of the counter sunk hole which was used for all important water tight rivets. In his description of the investigation of this matter the author does not refer to the flat head made by an entirely flat die and without counter sinking the hole. This rivet gives the greatest efficiency

against gas, water and oil under pressure and costs less to drive than any other. Was it not considered for this work?

The author mentions the use of special electric reaming machines for enlarging the shop punched holes to their correct size after gate material was assembled, and also the use of hand reamers for the same purpose. It would be interesting to know whether or not any single spindle electric or air driven reamers were used, and to have a comparsion of the results obtained from the different types of tools. It would also be very interesting to know just what form of reaming bit was found to be most economical, and especially whether of ordinary steel or alloy steel. The author fails to tell us whether or not all of the rivets driven in erection were driven by hand air hammers or whether compression riveters operated by air were used in some cases. A comparison of the results, if two types of tools were used, would be particularly interesting.

The operation of grinding at miter and quoin ends was in this case very extensive. Information as to the tools used and the results obtained would be particularly interesting.

The author mentions that in the adjustment of the miter bearing a difference of 0.021 of an inch was made between the top and bottom for the purpose of offsetting the effect of the water pressure on the bottom of the gate. It would be interesting to know how this allowance worked out in practice, and also whether or not a difference developed in the closure of the miter when different loads were on the gate, for instance, before the level of water in the lock became high enough to produce a weight on the top of the gate and when the maximum load was on the gate at high water level.

MR. W. C. COFFIN*: It is growing late and I will make my remarks correspondingly brief.

I am afraid that the last speaker (Mr. Duff) has asked for too much to be included in a paper such as can be read at one of our meetings.

I wish to congratulate the author of the paper for what he did include and for the interest that he has stirred up on the subject of fabrication of this peculiar class of steel work.

*Structural Engineer, Jones and Laughlin Steel Company, Pittsburgh.

I have been engaged in the business of fabricating water tight work for many years, and I find, as we do in other lines of industry, that many of our experiments are on lines that have been worked out over and over again by others. Of course we cannot always have the benefit of the experience of others, and again when working on new specifications we are fearful that the results reached elsewhere may not be fully applicable to the work in hand.

For instance iron and steel sheets have been pickled for many years and for many purposes, all sheets are pickled before being tinned or galvanized, so a great deal of data could have been secured in connection with pickling the lock gate plates, but they were doubtless afraid that it might not be exactly applicable to their work.

Then they found that gaskets would blow out and consequently they had to make recesses in the manhead castings for the gaskets. Every ship builder knows that and all porthole frames have recesses for gaskets. Watts learned it on his first steam engines, and recessed the cylinder heads to get the gaskets steam tight. Then they found that spiral gaskets were best which steam fitters learned many years ago.

The beveling of edges for caulking joints is called for in nearly all specifications, yet we learned years ago that square edges made a stronger and better job by using what is known as a split caulking tool, but it is still difficult to get engineers to permit the caulking to be done that way. I am glad that they finally got it adopted on the lock gates as the square edge is not only cheaper but is more mechanical and stronger.

The jogged and welded angle frames that were beautifully illustrated were not only interesting but show with what accuracy an experienced blacksmith can work and also make it quite clear that they could not have been made otherwise, as butted joints will leak, even though planed very accurately.

The punching of angles and bending them afterwards and yet securing perfect fitting is an art that requires only accurate figuring on correct principles. The old way of building iron oil tanks was to ship the shell plates punched but bend them in the field to the proper radius by simply pulling them around the

bottom angle. The bottom plates were not punched for the curved angle but were screw punched in the field after the angle was fitted on and the holes marked through it. This added a big expense and made the erection of the tanks a slow job.

It is but comparatively a few years ago since the Standard Oil Company entered the Kansas Field (about 1905). The Company I was connected with did not get in at the start, our price for tank material delivered was too high. The Oil Company did their own erecting. Presently we got an order and never stopped till we had furnished over six hundred 35 000 barrel tanks (95 ft. diameter). They paid us more per tank but their erecting superintendent reported that he was saving time and money because we punched all the holes in the shop and punched them to fit. Nevertheless we punched all the holes in the angles before bending and the holes in the circle of the bottom plates by a multiple punch. These tanks were not only cheaper to the Company after the erection was taken care of, but they were more satisfactory, and when it came to wrecking them and moving them to a new location it was reported to us that the higher quality of shop work was even more appreciated.

The above emphasizes the remarks of the last speaker about the work on the lock gates being evidently made right in the shop. It shows great economy always to see that this is done as the saving in the erection is more than the extra cost in the shop and the economy in not having extra work made necessary to secure acceptance by the inspectors is quite an item. The moral satisfaction in knowing that the work is right, is also reflected in the interest taken by the whole shop and field organization, and in securing greater efficiency from those forces not only on the work in hand but on subsequent contracts.

Mr. Archibald McKinley*: There are one or two questions brought up by Mr. Duff that I might be able to answer.

All the field rivets were driven with the ordinary riveting hammers and air buck-ups that we use on our erection work here in the States. Some attention was given to the design of special machines for this work but it was decided to use the regular equipment.

*Engineer, McClintic-Marshall Company, Pittsburgh.

In regard to the sagging of the leaf when swung on the pintle, the maximum deflection of any leaf at the miter end was 1/8 in. when all shores had been removed and the gate swung free.

As to the difference between the large power driven reamers and the air and electric reamers that can be handled by hand, it depends on how many holes can be reached with the large machines without reswinging the scaffolds. The scaffolds for these machines were large affairs with a narrow gauge track laid on them for the machines to run on along the side of the leaf. These large power reamers had two spindles which could be operated together on account of the regular spacing of the holes which, of course, gave us a large number of holes reamed in a day, but the amount of rigging and labor required to swing and operate these big machines I believe used up any saving they gave over the portable reamers.

Mr. Samuel E. Duff: That is what I wanted to get at, whether it would pay somebody to buy a lot of these machines.

Mr. Archibald McKinley: It would not—unless you had an enormous amount of work to do with little reswinging of the scaffolds necessary to carry and operate these big machines such as we used.

Mr. Samuel E. Duff: What do you use for the bits, ordinary carbon steel, alloy steel or what?

Mr. Archibald McKinley: The reamers used were three flute and five flute, all of high speed steel. The three flute were used exclusively on the large reamers and we had the five flute for the small reamers.

Mr. Samuel E. Duff: Do you remember the speed of the power driven reamers?

Mr. Archibald McKinley: The speed of these large reamers was variable.

Mr. E. W. Pittman:* I have not prepared any discussion of the paper but I happen to know in regard to the reamers that high speed reamers were used.

*Manager, Pittsburgh Works, McClintic-Marshall Company.

Mr. Samuel E. Duff: Where you had several thicknesses of material, could you use power reamers effectively on account of varying directions of the finished holes? You probably had some holes that you could not finish out exactly at right angles to the surface. Did you have any difficulty with the power reamer in deep holes?

Mr. E. W. Pittman: The horizontal electric power reamers were not used in such places but air reamers. The electric reamers could only be used in a direction normal to the plate.

Mr. Harry J. Lewis†: I do not know of anything that interested me more than the use of the square edge instead of the beveled edge for calking joints. In this case it was a matter of water pressure only and not over forty pounds per square inch at most. When the joint was made tight there was not likely to be much need for another calking as in the case of a steam boiler where even a beveled edge is sometimes turned into an overhang by repeated calking.

Mr. W. C. Coffin: I can answer Mr. Duff's question as to the mode of operating the gates, both from seeing the detail drawings and also from an inspection of the operating apparatus.

The mechanism could not be more simple. It consists of a steel arm, attached near the top of each leaf and about one-third the way out from the hinge center. This arm is fitted with a rack that meshes with a large gear wheel.

Between the motor and this wheel is a set of gears which reduces the speed perhaps five hundred to one. The rack swings in and out on the gear wheel, either pulling the gate open or pushing it shut.

Mr. P. E. Hunter*: I would like to ask whether the concrete was placed around the quoin reaction bearings before or after the gate was set; also as to whether the angles forming the frame of the bulkheads were planed where they came in contact with the webs of horizontal girders and the sheeting plates, or whether the rolled edges were simply calked against the webs and sheeting.

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*President, Independent Bridge Company, Pittsburgh.

The Author: The quoin castings were placed before the walls were built and were concreted in when the walls were poured. The bearing plates in these castings were erected by the lock gate contractor but were assembled and adjusted before any of the gates were erected. This work was performed while the erection equipment for the gates was being assembled.

Mr. Hunter has also raised the question about the angles on the watertight frames. These angles as well as all others which had to be calked were planed as it was considered that the rolled edges would not be as sharp and well defined as was necessary to obtain satisfactory results in calking.

Mr. Duff has brought up several matters not treated fully in the paper. To go into all of these as thoroughly as their importance would warrant would take an entire evening in itself. The great difficulty in presenting a paper on this subject was found to be in deciding what could be omitted to reduce the length of the paper so that it could be read at a single session of this Society.

I regret that I am unable at this time to do justice to the subject of deflection of the gates and to the compression of the arch ribs as brought out by Mr. Duff. All such computations were performed by the Engineers of the Canal Commission on the Isthmus. In the computation of stresses the girders were not considered as taking the water pressure for the half panel just above and below, but the deformation of the entire gate was considered as having effect on the stresses in the individual girders and frames. This was considered necessary because the upper girders in each gate were considerably heavier than necessary, as it was deemed advisable to use no material in them less than $\frac{7}{16}$ in. thick. These girders with the vertical frames would thus assist the girders further down in which there was no excess metal. Then again, under full pressure, the sill at the bottom of the gate would transfer some load to the fixed sill, thus complicating the action of the internal stresses. To take these matters into consideration, the elasticity of the entire gate had to be considered, and the gates were therefore figured as statically indeterminate structures. This required the solving of as many equations as there were girders in a leaf. As these

equations were long and complicated, it can be readily understood that these computations became rather laborious. The theory on which the computations were based I believe is similar to that outlined in Molitor's Kinetic Theory of Engineering Structures, Chapter XIV.

Mr. Duff has asked for information in regard to the punching of this work. He has called attention to the fact that without the use of spacing tables the great accuracy obtained would have been impossible and that the amount of time required to execute the work under the old time method of laying out would have been prohibitive. In punching the greater part of this work Conley Spacing Tables were used. This, as has been pointed out, resulted in much more accurate work than with the old time system of laying out, for once the punches and stops are accurately set, it is absolutely impossible to deviate from the desired spacing, whereas in punching work laid out, the operator sometimes thinks that it is only necessary to punch out the center punch mark. This method of punching eliminates the work of the layerout and consequently the extra handling of material involved thereby. This allows so much more floor space to be used for other purposes.

In regard to the pan head rivets, I believe that this term is not used in boiler and tank work. It is, however, used in ship building, and standards for such rivets are to be found in the United States Naval Standards. The height of a $\frac{7}{8}$ in. rivet of this type is 9/16 in., the large diameter $1\frac{5}{16}$ in. and the small diameter $\frac{7}{8}$ in. In driving these rivets a button set was used, causing the pressure to come on the edge of the head, thus forcing down the rim and by this, reducing the likelihood of water getting under the head. There was another type of rivet used called a tap rivet, which corresponds, I believe, to the boiler patch bolt of tank makers. These were used wherever it was impossible to use ordinary rivets on account of the interference of some part of the structure. These rivets were threaded and provided with a countersunk head. There was a small square shank projecting from this head used for screwing in the rivet and which ultimately had to be cut off. The question of using flat head rivets to which reference has been made, I believe was never discussed.

With reference to the lack of necessity of changes in design, attention has not been called to the fact that changes were necessary. The principal one was in the design of the pumping system. As originally designed, there was to be an air tight sump chamber built into the bottom compartment of each leaf. The drainage pipes leading to this were controlled by valves which were to be closed when it was necessary to pump water out. This pumping was done by forcing air into the pump chamber through one pipe which would force the water out through another pipe. The pump chamber was finally omitted, the water allowed to drain to a sump in the center and a centrifugal pump installed.

Another change was in the construction of the ends. It was found very difficult to obtain a satisfactory construction at these points and it was only after considerable study that the arrangement finally used was adopted. The difficulty was due to the fact that the constant distance between the end reaction castings and girders had to be filled up with sheathing plates, bent plates, doubling plates and wedges which varied considerably in thickness, part of these plates running horizontally and part vertically. Also to the fact that the two sides of a leaf could not be considered independently because of the bent plate tying the two sides and end together; added to this, consideration had to be given to arranging the construction so that all joints could be made watertight.

Attention has been called by Mr. Duff to the fact that the design was so made that great duplication of parts was found possible. This was done not only to secure a low price for the fabrication of this work but also to reduce the number of spare parts which it would be necessary to keep on hand to repair any ordinary damages.

With reference to the nickel steel bearing plates, I believe that nearly all the gates built have been constructed with wood bearing. In designing the largest of the gates for Panama it was found that the pressure was so great that wood could not safely be used. It was therefore decided to use the nickel steel bearing plates for all gates, although the wood would have been satisfactory for the smaller gates.

After the lock gates were nearly finished in the shop, the designs were received for a gate of exactly the same length and outline but only 57 ft. high to be used at the entrance of a drydock at Balboa. On this gate wooden bearings were used. It has always seemed to the speaker that, although these gates were not gotten out at the same time as the lock gates, that in order to make it possible to use the spare parts from the lock gates, that they should have been made exactly the same. The construction at the end on account of the use of wood bearings was entirely changed so that very few of the spare parts furnished for the lock gates can be used for the drydock gate.

Mr. Coffin has called attention to the fact that several of the matters investigated in connection with this work have been threshed out years before with the same results. The points investigated were considered of sufficient importance to warrant such investigations. It should be remembered that the amount of work included in this contract was enormous and that the erection had to be performed in a tropical country at a long distance from the shop and main office. Before starting the pickling operations, an effort was made to find out from those engaged in such work what was the best practice to follow. An engineer was sent around to make an investigation of several plants. His report showed such a great diversity of practice that it seemed best to make the experiments already outlined.

Referring to the matter of recessing watertight covers for gaskets, attention should be called to the fact that the original designs had to be followed until it was demonstrated that they would not give satisfactory results. An effort was made in the beginning to have the covers changed to the type used in ship building work where the gasket is fastened positively to the cover. This, however, was not permitted by the Commission on account of a small increase in the cost.

Mr. Coffin has also called attention to the fact that it has been known for years that beveled edges for calked work were not necessary, but that engineers in charge of such work could not be so persuaded. Permission was obtained from the engineers in charge of the lock gate work to omit the beveling with the understanding that the contractor would obtain satisfactory

results and that unless such results were obtained beveled edges would have to be used.

A word might be added in regard to the fender chain. This chain will normally be stretched taut across the canal. A vessel approaching under its own steam will have to be stopped before the chain will be lowered into a recess in the bottom and side wall. The vessel will then be towed through an electric mule running on tracks on both sides of the lock. This chain is very large, made up of 3 in. iron and is designed to stop one of the largest ships traveling at a considerable speed in a distance of 70 ft. The design of the construction necessary to secure such results is very interesting, as a considerable amount of experimenting and testing was done before the final design was adopted. I believe that a paper on these chains would be of interest to the Society.

Mr. Duff has inquired in regard to the field riveting. These rivets were all driven by pneumatic hammers. The compression type of riveter was considered for part of this work and a design of a special riveter for this work was made up. It was, however, abandoned, as it was found impossible to keep the weight of the machine within the limits deemed necessary for economical use.

Mr. Samuel E. Duff: I think Mr. Pendergrass ought to tell us how he could have punched those gates in single punches. If he did not have any spacers how could he have gotten those comparatively thin skin plates and battens or reinforcing plates and the girder flange angles to fit in 50 ft. lengths on account of the stretch of material? I want to bring out the importance of the accurate punching of these different parts in connection with the correct general dimensions so easily obtained. That has not been brought out here at all. That is the real point. On account of the length of the material, if the different thicknesses had been punched on a center punch, they never would have fitted at all; whereas by this method of punching used by the contractors, the stretch of the material does not affect the spacing of the holes.

The Author: I do not believe I could tell that story as well as Mr. Duff can, for the reason that my experience has been

pretty nearly exclusively of the later type. Since I have been with the Company all the work has been punched with the rack punches. There is very little work that I have done that has not been so punched. That is one of the difficulties we have to overcome in making a shop drawing on a good deal of work, as it is very often designed without any consideration for rack punching, and we have a great deal of trouble in adapting details of spacing, etc., to suit these punches, but as far as getting results are concerned, we certainly do get very fine matching of the holes.

Mr. P. E. Hunter: The question of relative cost of rolling or floating and miter gates has been raised, and having built a great many of the different kinds, and erected them in all parts of the country, I can answer the question in a general way.

The floating gates—the best example of which are the bear trap gates used on the Ohio River to regulate or control the height of pool and to draw off the debris gathering at the dam—would cost about the same as a rolling gate, taking foundations, etc., into consideration; but could hardly be considered practical for locking boats through the lock chamber, and particularly so where the height is over eighteen to twenty feet.

The rolling gate is generally a vertically framed gate, having a truss or girder across the top taking approximately 33 to 40 percent of the pressure; depending principally on the connection of verticals to truss or girder, whether hinged or rigid—the balance being transmitted by a system of vertical members to the flanges of wheels bearing against a gate track set and anchored in concrete. This gate is better adapted to places where the length is much greater than the height, as the vertical members being short would be much lighter than the long horizontal girders of the horizontally framed type.

Generally speaking, the rolling gate will cost about 30 percent more than the miter gates, this percentage increasing with the increase in the height of lift in the lock. I might also mention that there is a saving of about 5000 cu. yd. of concrete and probably 50 000 lb. of steel work where a miter gate is used instead of a rolling gate for the heights of gates as used on the Ohio River; the saving in concrete being due to the doing away

with gate recesses, and that of the steel to doing away with the gate track, ties, etc.

As to the amount of duplicate work in the different types of gates, would say that there is very little in the rolling gates as compared to miter gates, and that the complications are very much greater, due to the mechanical parts, requiring axles, wheels, springs, housings, links, etc., and also on account of obstructions from time to time on the track.

Where the erection of a rolling gate is being supervised by someone thoroughly acquainted with the engineering end of the work there should be no more delay or trouble in erecting them than in the miter gates, but very careful attention must be given that each piece goes into place in the proper order, otherwise it will be a case of tearing down and try again.

I have found that where rivet spacing is four inches or less, holes reamed one-eighth of an inch or more larger than the punched hole, and red lead used plentifully under butt straps, will render the joints along straps water tight where a height of 25 or 26 ft. is not exceeded.

The air reaming on this heavy work is very costly. We built certain reamers according to our own ideas, using a 6½ h.p. motor and single spindle, and were able to cut down the cost of reaming 75 percent. Two men are able to handle the machine. Most gates are being specified with holes sub-punched $\frac{3}{16}$ in. smaller than the size of rivet, requiring ¼ in. to be reamed out. With these electric reamers we found two men could swing around the work and remove the amount required very easily.

The lining up of quoin and miter posts is a very difficult operation, and I undestand on the Panama gates the adjustment was obtained by adjusting one side, but this has been improved upon since by making possible adjustment on each side. I do not approve of a construction where the quoin reaction bearing is placed before the gates, but am very firmly of the opinion that the leaves should be swung on their pintles and adjusted to their final position with relation to each other, and while in a closed position adjust the quoin bearings and sills to the leaves.

As the quoin thrust castings are made in sections, the quoin bearings should be also castings in sections made about one-eighth of an inch less in length with provision made in the design to fasten the bearing castings to the thrust casting, leaving an eighth of an inch between bearing castings at the joints of thrust castings, thus doing away with the field grinding. After the gates are adjusted with these castings in place the concrete can be placed around bearing castings, and when properly set the tap bolts from thrust to bearing castings can be removed, permitting leaves to swing.

The point raised by Mr. Duff regarding effects of pressure and deflection of gate leaves are points of extreme importance in the setting of the gates as well as in the design, but are sometimes overlooked as inspectors are seldom aware of the importance of them, and the designers seldom see the work during progress of construction.

In the design of gates provision must be made for compression of the leaves due to thrust of water as well as the load on each horizontal girder due to water pressure against it. This water pressure varies according to depth, but only directly when the leaves are in miter but not bearing against the sills. Under such conditions the horizontal girders from the surface of the lower pool to the bottom of gate would be of the same strength, and those from lower pool level to upper pool level would decrease in strength in proportion to depth. But as it is necessary for gates to bear against the sill to obtain a seal the vertical rigidity of leaf changes the forces, causing the pressures to be distributed somewhat differently, those at the top being increased, and it being patent that if the lower girder bears on the sill the girder would be relieved of its load. As the temperature of the water and pressure against the gate affect its length, the gates might be set with perfect contact at sills and miter, and due to change of temperature or pressure, or both, might have good contact at miters and none at sills; or might fit the sills and have poor contact at the miters. Such being the different conditions under which the gate may be affected it is proper to design the girders for the maximum stress they may be required to stand due to depth below the surface or due to the vertical rigidity of gate.

The deflection or sag of the leaves is taken care of by the sheeting plates and diagonals designed for that purpose, but it should be kept in mind that this feature can be taken care of entirely only in the erection of gates, and is a strong argument why quoin bearings should be set only after leaves are erected and adjusted to each other.

My experience in the building and erection of gates has led me to recommend to the engineers in charge of work that I be permitted to erect the leaves with girders level and posts plumb; to move leaves in resting them on their lower pintle and attaching anchorage to top pintle, swinging leaves and adjusting anchorage until the miter posts touch at the bottom, and have an opening of from one-quarter of an inch to three-quarters at the top, depending on the height of gate and its rigidity—the more flexible the leaves the larger the opening, as the pressure will deflect the tops of leaves at unsupported ends down stream, bringing them together.

If any sagging should occur later at the miters they will always form a contact before touching the sill if sill is properly set. The sill should be set against the gate at the quoin end when gates are closed, and from ¼ in. to ½ in. away from gate at miter end; this distance depending on temperature at time gate is set, length of leaves, whether sill has cushioning strip, stiffness of lower girder, etc. Part of the opening will be taken up by compression on leaf, part by deflection of lower girder, and part by any sagging of gate that may take place in the future.

The quoin bearings are then concreted in, and inasmuch as the leaves were being carried in their working condition with strain on pintles and anchorage due to their weight, the construction must prove satisfactory.

I want to ask the writer as to the idea of using a two inch hose in testing. I have erected many of the bear trap gates in the Ohio River and tested these on the inside, using a ½ in. nozzle under 100 to 125 lb. pressure, and they rise with a head of from 14 to 18 inches of water.

The Author: Two inch hose with one inch nozzle was specified by the government engineers. I do not know what

their reason was. While they did not say that was to be applied to the outside, it was so understood. We felt that the method adopted would prove a severe test and one which would show up exactly where the leaks were.

Mr. Harry J. Lewis: I think possibly the point Mr. Duff has in mind with regard to the spacing machine in punching is that when material is laid off from template and punched, the distance between holes is the distance on the template plus the stretch in punching; while with the spacing machine the material is simply pulled along by a carriage moving on a graduated metal track and the spacing of the holes is done by simply stopping the carriage at the right place for each hole. By this latter method the stretch from punching each hole is corrected in each space and the hole is the right distance from the first hole within the limits of accuracy of the graduation rack.

RECENT DEVELOPMENTS IN THE HEAT TREATMENT OF RAILWAY GEARING

By W. H. Phillips.*

The heat treatment of steel dates back many years but it has only been within the last decade that really important strides have been made. The steel man of yesterday with his equipment of human pyrometers, incorrectly designed furnaces and limited testing apparatus, if he did succeed in producing a good piece of steel properly heat treated one day, might not necessarily produce a like product the next.

In the early days, machine parts were designed with a sufficiently high factor of safety for irregularities of material and treatment while to-day, when the cost of extra weight, the additional expense in carrying this weight in moving parts, and the limited space for these parts are considered, it becomes necessary to go to a stronger material of a more uniform quality. These demands have resulted in improved methods of manufacture. By the aid of the better equipped chemical laboratory and what is even more important, the metallurgical laboratory with its high powered photo-micrographic outfit where the steel may be examined after each step through the process and the results checked and compared; and with the great store of experimental data so carefully correlated, the heat treatment of steel is gradually coming out of the rule of thumb class to that of a science.

There are many remaining points that still have to be investigated and developed, but, nevertheless, the work accomplished has been very encouraging.

In the whole field of heat treatment of steel, we believe that no greater progress has been made than in its application to railway gearing. In this work the tendency has been to reduce

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the width of the gear face even while greater loads and higher speeds have been imposed upon it.

The automobile manufacturers have been able to meet these new problems by introducing the alloy steels. Their parts are relatively small and the difficulties experienced in shrinkage strains, treatment cracks and distortions are not as serious nor as difficult to overcome as when the part to be treated weighs several hundred pounds.

Either of these two most important classes of large and small gearing would give sufficient data for this paper; therefore, only the city and interurban motor gearing will be considered.

A relatively small development has been attempted with alloy steel for railway motor gearing, which has met with varying degrees of success. Undoubtedly the future holds in store some interesting developments along this line, but carbon steel has not yet been developed to its limit and the improvement which is to be expected, will probably meet the demands of the trade for some time to come.

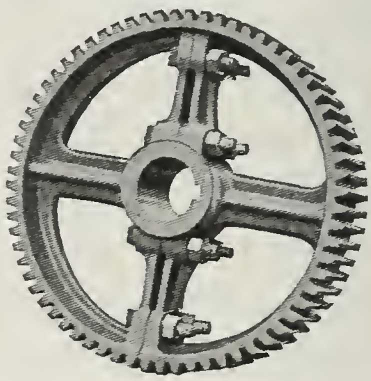


Fig. 1. Cast Iron Gear.

The method of steel manufacture most used at present is the open hearth process, although the electric furnace gives promise of a further advance as a source of supply of raw material for the carbon steel type, since it is claimed to be much freer from segregation, oxide and dissolved gases, such as hydrogen and nitrogen. Electric furnace steel is, however, a comparatively new process and the sources of supply are limited. The treatment required for this steel is much the same as for open hearth steel and its physical properties are also similar except that tests show electric steel to have a higher resistance to fatigue.

DEVELOPMENT OF THE RAILWAY MOTOR GEAR

Twenty-five years ago the street car was of little engineering interest. It had a seating capacity of 12 to 16 persons and was drawn by horses at a speed of from four to six miles per hour. To-day the modern interurban trolley car weighing 50 to 60 tons, with its high speeds, many stops and a seating capacity of 60 persons with a strap hanging capacity of that many more, presents a problem in gearing that is of no mean importance.

Fig. 2. Malleable Cast Iron Gear, Solid.

The steady increase in the power and size of the motor, the track gauge having been fixed, tends to cut down the available space for the gear. As for example, by adding ½ in. more to the length of a 10 in. armature, the power is increased, we will say, 5 percent. If this ½ in. is taken from the 5 in. gear face, its available working face has been reduced 10 percent while it has to do more work, or a 17 percent increase in pressure per inch width of face.

The early electric street cars were equipped with 20 to 30 horse power motors. To-day motors of 250 horse power are in

use, while motors up to 300 horse power are contemplated with about the same or even less space for the gear.

A brief outline of the evolution of railway motor gears in the order in which they were introduced on a commercial scale may be of interest; viz: Cast iron, malleable cast iron, semi-steel, four spoke open hearth cast steel, six spoke open hearth cast steel, forged open hearth steel, electric furnace cast steel and lastly the flexible gear.

CAST IRON GEAR

The cast iron gear, shown in Fig. 1, was cast with the rim solid, the teeth being cut by the manufacturer. The design was such as to cause numerous scale spots, shrinkage cavities and shrinkage strains.

Fig. 3. Malleable Cast Iron or Cast Steel Gear, Split.

The shrinkage cavities occurred at the center of the greatest mass of the metal, which usually came outside of the root of the tooth circle. These defects, together with the low strength of the iron, caused many failures and, as the motor power became greater, this grade of gearing had to give way to a stronger material. The tensile strength of cast iron is from 20 000 to 30 000 lb. per sq. in. with very low ductility.

MALLEABLE CAST IRON GEAR

The malleable cast iron gear, shown in Figs. 2 and 3, had some advantage over the cast iron gear. It was less subject to shrinkage strains and was more ductile, a common selling point being to bend a tooth over on to an adjacent tooth without crack-

ing or breaking. Most of the defects common to the cast iron gear, however, are also prevalent in the malleable cast iron gear and it soon had to give way to the steel gear. Its tensile strength was approximately 40 000 lb. per sq. in., its ductility somewhat higher than cast iron, but in a like manner to cast iron, had to give way to a stronger material.

Semi-steel was then tried, but with little success on account of non-uniformity.

CAST STEEL FOUR SPOKE GEAR

The four spoke cast steel gear, shown in Figs. 3 and 4, is cast either split or solid. The split design allows the gear to be applied to the axle without removing the wheel and since all solid gears have to be pressed on the axle, the split design is used by small operating companies not equipped with a wheel

Fig. 4. Cast Steel Gear, Solid.

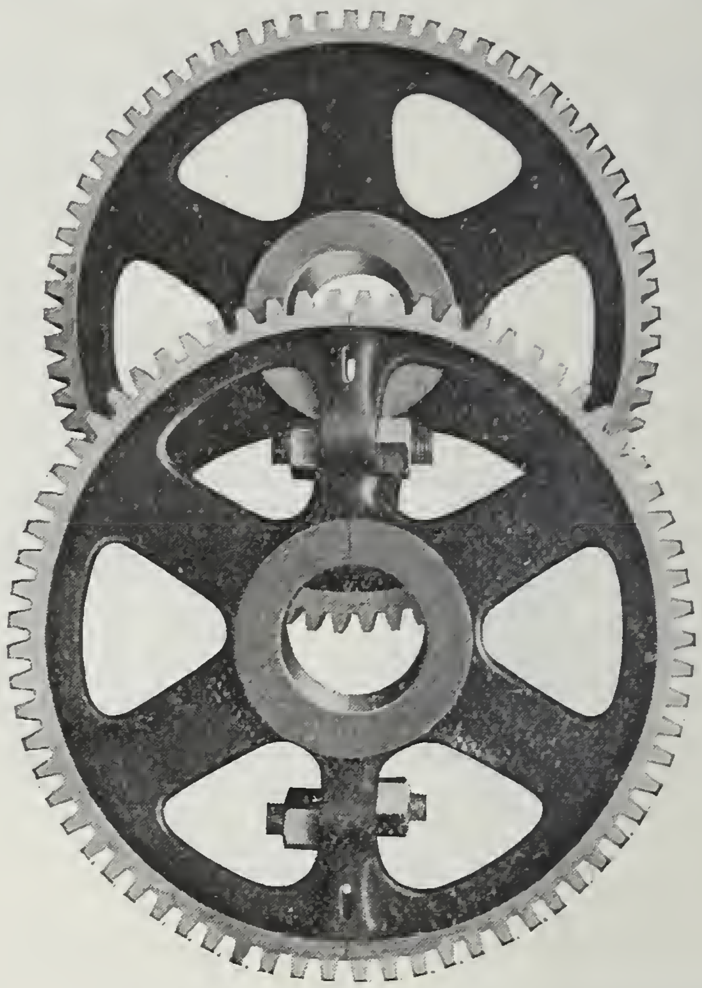
press. The steel casting was much stronger than the cast iron or malleable iron, yet the defects common in castings were still prevalent. The introduction of heat treatment of gearing at this time greatly improved the physical properties of this gear. The treatments applied were oil quenching and case hardening.

Below is given a table of the physical properties:

	Normal	Oil Quenched	Case Hardened
Ultimate strength	60 000 lb.	75 000 lb.	....
Yield Point	30 000 lb/	45 000 lb.	....
Elongation in 2 in.	14%	18%	....
Reduction in area	30%	40%	....
Brinell Hardness	130	202	555 to 655
Scleroscope			85 to 95

SIX SPOKE CAST STEEL GEAR

Many different designs of the cast gear were tried out in an effort to overcome shrinkage cavities with varying degrees of success, the most satisfactory result having been accomplished by the R. D. Nuttall Co. through the introduction of the six spoke design, shown in Figs. 5 and 6. The section is nearly uniform throughout, the spoke being oval in shape. A bead on the under side of the rim brings the center of the mass of the



Figs. 5 and 6. Six Spoke Cast Steel Gear, Solid and Split.

rim blank well inside of the root of the tooth circle, and since the shrinkage cavities occur at the center of the mass, they are well away from the danger zone if any does occur in the six spoke design.

THE FORGED STEEL GEAR

The next and most radical step in the design of the gear was the introduction of the forged blank, shown in Figs. 7, 8 and 9. This design has many advantages over the cast steel design. All of the casting troubles are eliminated and when properly worked, the steel has a fairly fine grain and is free from blow holes.

Due to the greater strength of the material, the forged gear could be made lighter than the cast gear. Undoubtedly the present design of forging will be greatly improved in the near future.

Fig. 7. Forged Steel Gear Blank.

There are two methods of manufacturing the forged blank —rolled, and hammered and rolled.

THE ROLLED GEAR BLANK

In this process the ingot is heated and rolled into a round about 12 to 18 in. in diameter and cut into discs from 6 to 10 in. thick, depending upon the size of the blank to be rolled. These

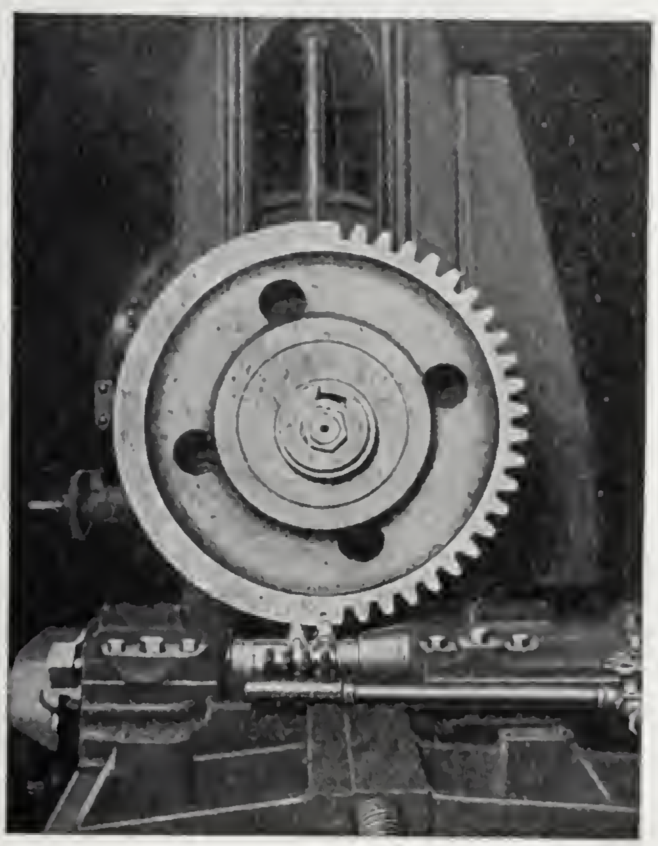


Fig. 8. Forged Steel Gear, Cutting.

discs are again heated in a continuous heating furnace and a mandrel is punched nearly half way through the center of the disc. It is then placed between two vertical dies set at an angle in such a way that the steel is worked from the center towards the rim, the dies rotating synchronously. There is a slight dish in the web of the gear and generous fillets between the hub, web and rim are provided.

THE HAMMERED AND ROLLED GEAR BLANK

This process consists in casting an individual ingot which is hammered into a flat disc of the required size. The center with any pipe or segregation is punched out and the disc is pressed into a rough semblance of a gear blank with sufficient

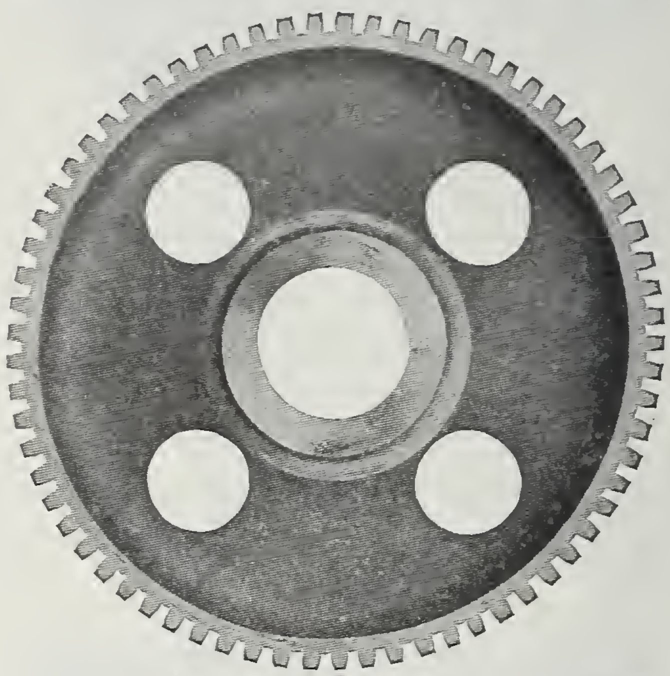


Fig. 9. Forged Steel Gear, Finished.

metal in the rim to form the web and rim of the finished blank. This heavy rim is then worked out to the desired size between a set of rolls compressing it on all sides. The web of the blank is straight.

The physical properties of the forged steel gear are shown in Table No. 1. These treatments will be described later.

	Normal	Oil Treated Med. Carbon	Oil Treated High Carbon	Case Hardened	B. P. Process
Ultimate Strength	75 000 to 90 000 lb.	90 000 to 110 000 lb.	120 000 to 140 000 lb.	*	120 000 to 140 000 lb.
Yield point	35 000 to 50 000 lb.	60 000 to 75 000 lb.	75 000 to 90 000 lb.	*	75 000 to 90 000 lb.
Elong. in 2″	20 to 30%	12 to 16%	8 to 12%	*	10 to 14%
Reduc. in area	35 to 50%	35 to 50%	20 to 30%	*	30 to 40%
Brinell	176	207 to 287	302 to 387	555—650†	418 to 555

*Impractical to obtain pulling test.

†The Brinell test of case hardened gearing is not as representative as the Scleroscope reading which is 85 to 95.

FLEXIBLE GEAR

During the development along metallurgical lines, the engineer has been busy and the flexible gear, shown in Figs. 10 and 11, is the result of his labor.

The Westinghouse engineers, realizing that railway gears are subject to sudden peaks of overloads, have devised a practical flexible gear to relieve these enormous shocks. The flexible gear has many other mechanical advantages which will not be taken up here.

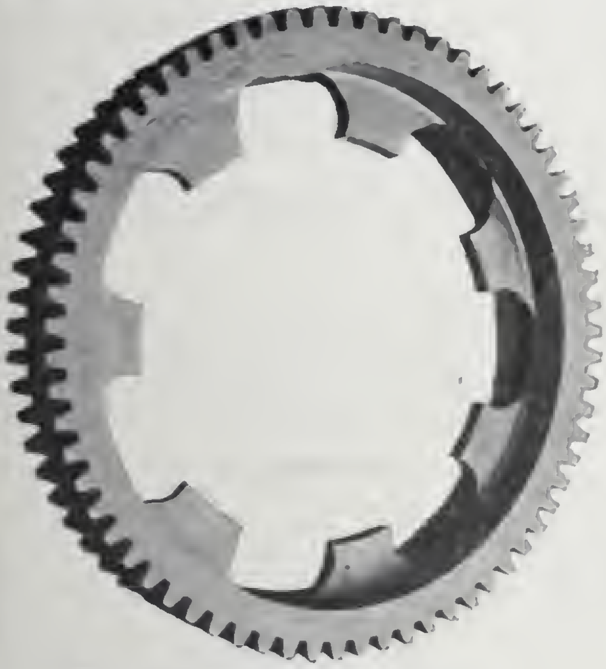


Fig. 10. Forged Steel Rim of Flexible Gear.

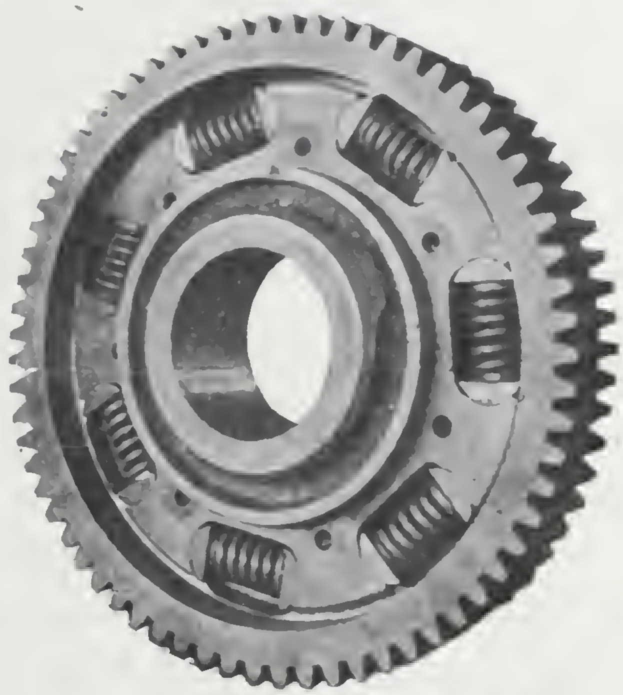


Fig. 11. Flexible Gear with Springs Assembled.

The principle of the flexible gear involves the transmitting of the power from the gear through a series of springs to the axle, these springs being interposed between rigid lugs on the inside of the gear rim and the gear center which is in turn pressed on the axle.

This gear has met with great success and it is apparent that the principle will be widely employed in the future for heavy duty railway gearing.

DEVELOPMENT OF THE PINION

The development of the pinion, while it has not been so radical as that of the gear, yet is important enough to be mentioned. The first railway motor pinions were made from bessemer rolled round bar, the blanks being cut off to the desired thickness. The R. D. Nuttall Co. were the pioneers in the treatment of motor pinions and used this grade of steel. .The bes-

semer process was soon replaced by the open hearth process. These materials in the form of rolled bars developed imperfections that made their use for pinions inadvisable.

The forged bar was the next step. Two methods of forging blanks for pinions are used—the hammer method and the press method.

HAMMER FORGED

In this method the ingot is either first rolled into a billet, the billet being hammered into a bar nearly to size under flat dies, rounded up and cut to length, the steel getting a thorough working; or the ingot is rolled into a billet, cut into short lengths and upset. For example a 4 in. x 4 in. billet is cut into pieces 10 in. long, upset to the required thickness and rounded up under the hammer.

PRESS FORGED

In the press forged method the steel may be handled in the same manner as when forged under the hammer, the material, however, being worked under a press.

THEORY OF TREATMENT

One of the first essentials in the heat treatment of steel is to know the composition of the steel to be treated. All steel for heat treatment should be purchased on chemical analysis and check analysis of every heat carefully made before treating.

While good commercial steel contains, beside the carbon, such elements as manganese, sulphur, phosphorus and silicon, and even though they have more or less effect on the heat treatment, they will not be considered here. The two principal constituents of carbon steel are pure iron and carbon. Upon the amount of each of these two elements together with the manner in which they are combined and also the size of their crystals, depends the strength and ductility of the steel. Iron may exist in three forms, namely, Alpha or strongly magnetic iron; Beta or faintly magnetic iron; and Gama or non-magnetic iron. Carbon may be in the steel either as a solid solution of carbon in iron or as a definite chemical combination (Fe_3C) cementite.

A typical heating and cooling curve is shown in Fig. 12. The *AC* and *AR* points indicating the critical temperatures on heating and cooling respectively.

The temperature at which the steel is treated governs the above information and is shown graphically in Fig. 13 where the temperature is plotted as ordinate and the carbon as abscissa. For example, a 0.20 percent carbon steel is cooled from the molten condition and the heat cycle observed. It will be noted that as each unit of heat is extracted, the temperature drops uniformly until at some point such as A_3. Although the heat

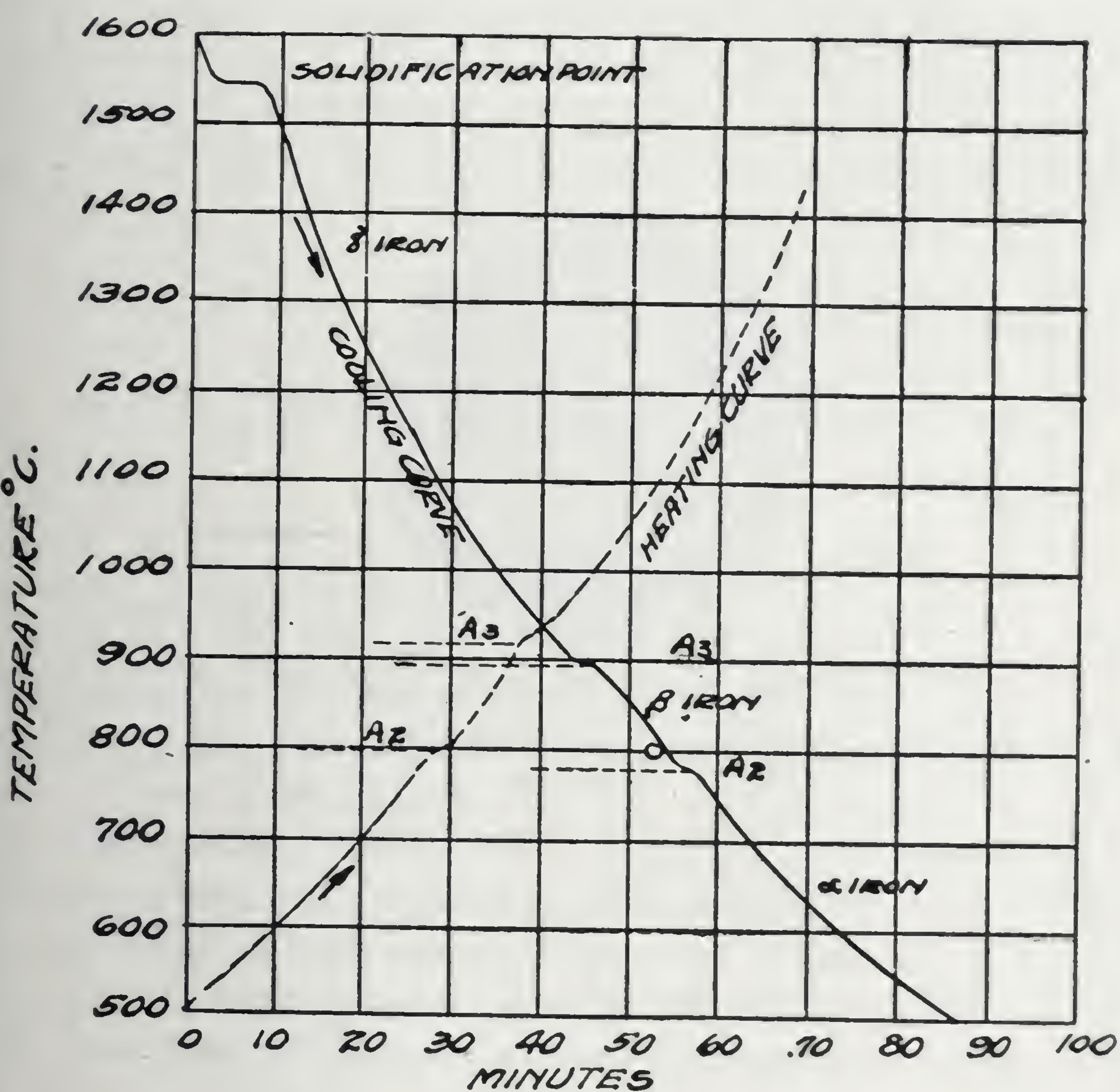


Fig. 12. Heating and Cooling Curves.

is still being extracted, there is no drop in the temperature of the steel. The steel may even become hotter, denoting some internal chemical change or rearrangement of the crystals. This phenomena occurs again at some such point as A_2, but to a less marked degree, and again at A_1 with about the same evolution of heat as at A_3. It will be noted that at about 0.35 percent carbon A_3 merges with A_2 forming $A_{3\text{-}2}$ and again at about 0.85 percent carbon $A_{3\text{-}2}$ merges with A_1 forming $A_{3\text{-}2\text{-}1}$.

These points are called the critical points in steel. Due to a certain hystereses or lag in the steel, they occur at a higher temperature in heating *AC* and a lower temperature in cooling *AR* thus making it probable that the *AC* and *AR* points are at opposite ends of the same phenomena. The so-called range lies between the extreme high and low critical points.

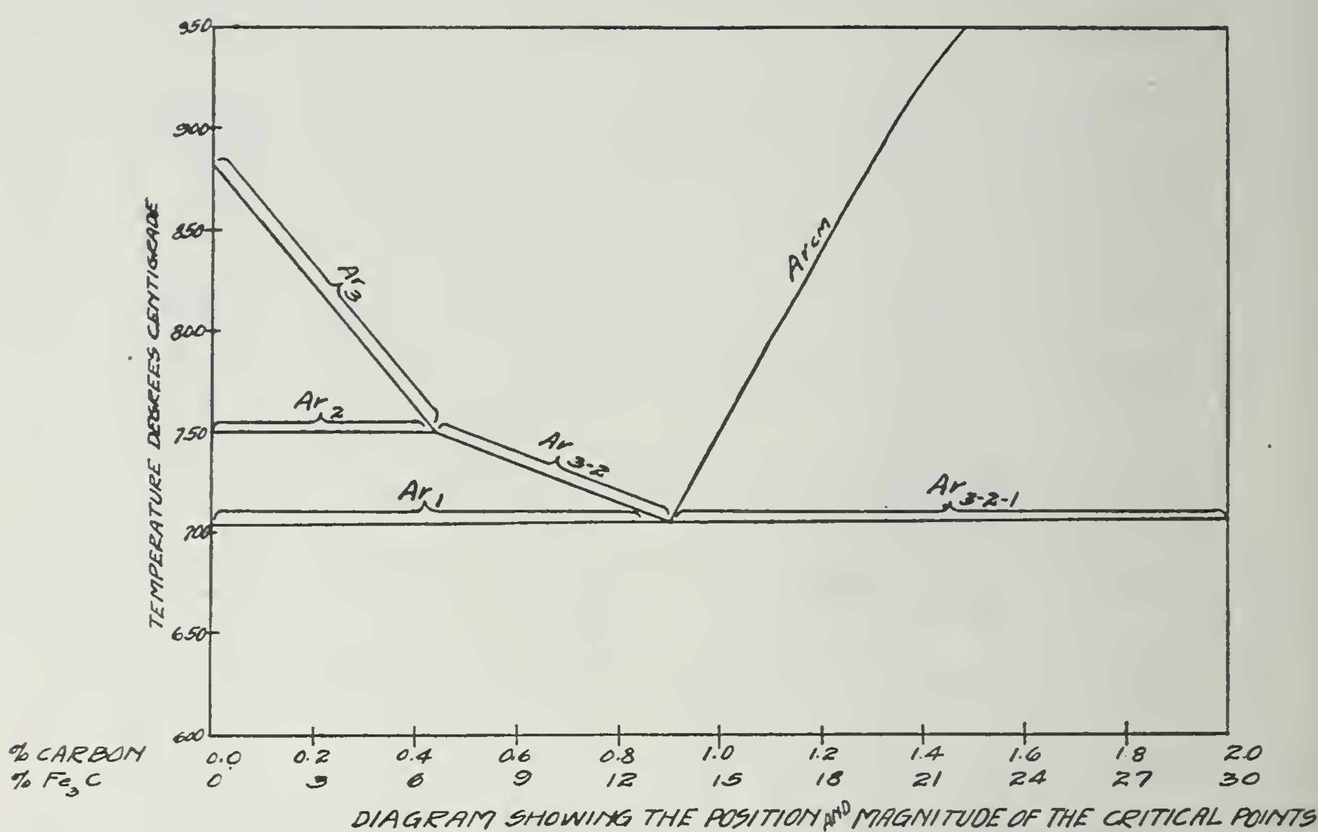


Fig. 13. Diagram Showing Position and Magnitude of the Critical Points.

Steel when at a temperature about the critical range is a solid solution of carbon in iron or austenite and when quenched from this temperature the result is some form of solid solution of ferrite and cementite or carbon, depending upon the rapidity of the cooling which in turn is controlled by the quenching bath.

Martensite is produced by sudden cooling from above the critical range, is hard and brittle and is thought to be a solid solution of Alpha iron and carbon with Beta iron.

Troostite is a transition stage between martensite and sorbite and is less hard and more ductile than martensite.

Sorbite is a transition product formed between troostite and pearlite. The amount of any one of these transition products retained in the steel after quenching depends upon the rapidity with which the heat is extracted by the quenching

bath and as these products are unstable, they can be tempered or drawn back at low temperatures to the hardness desired.

The general methods of heat-treatment of steel are the same for different grades of steel and the sequence of operations being: Annealing, quenching and drawing.

ANNEALING

Annealing is provided before machining in order to eliminate casting or forging strains and to facilitate machining. The furnace when charged must be at a temperature that will not produce deleterious stresses due to uneven or sudden expansion of the exterior as compared with the expansion of the

Fig. 14. Oil Tempered Tooth Broken to Show Structure.

interior of the steel. This feature becomes more important with the increase in size of product and experience must be drawn upon to determine what the charging temperature and rate of heating must be for the various shapes and sizes to be annealed. The gas is turned on and the furnace brought up to heat very gradually, so that when the pyrometer indicates the proper temperature, only a short soaking time is required to bring the full charge to the temperature indicated. When the gear has reached the proper temperature, it should be drawn from the furnace and covered with dry sand or ashes or preferably, if convenient to do so, allowed to cool slowly in the furnace. Either method will prevent the setting up of cooling stresses. Practically all of the machining operations are performed while the steel is in the annealed condition.

QUENCHING

The same precautions taken when heating for annealing must be observed when heating for quenching, the temperature

aimed at being slightly above the critical range. The higher the temperature above the critical range and the length of time held at this high temperature, the coarser the crystaline structure. The difficulty experienced in holding the temperature uniform and the length of time required to quench, makes it necessary to limit the size of the charge.

The gear is transferred quickly from the furnace to the quenching bath to minimize the loss of heat in the gear while being transferred and to eliminate the over heating of the remaining gears in the charge. The loss of heat, ascertained by means of the optical pyrometer, is taken into consideration when estimating the proper furnace temperature. The quench is made in such a manner as to allow the greatest surface area of the

Fig. 15. Case-Hardened Tooth, Polished and Etched to show Depth of Case.

gear to come in contact with the bath at the same time. This produces a minimum distortion and eliminates the necessity of re-cutting the teeth after treating. The time in the bath must vary with the size and design. The parts should be removed from the quenching bath after the temperature has dropped below a certain point, varying with different steels. Further quick cooling is unnecessary and may set up injurious stresses.

DRAWING

The last operation in heat treatment of steel is the drawback or tempering, which should be done immediately after quenching. This may be done in a furnace or in hot oil.

The gear should be removed from the quenching bath to the drawing furnace or hot oil bath and held at a pre-determined temperature for a proper time depending upon the grade of steel

used in order to relieve stresses and to obtain the structure desired. The oil bath should be used for drawing at low temperatures and the furnace should be used for drawing at high temperatures or those above the fire test of the oil.

The following four general classes of gearing will be discussed in the order given:

1. Normal
2. Oil Treated
3. Case Hardened
4. B. P. Process.

1. *Normal*: Normal or untreated gearing consists ordinarily of medium carbon steel (cast or forged) for such service as does not require the refinement of heat treatment or when first cost is the governing factor. The approximate physical properties of *normal* forged steel gears are shown in Table No. 1.

2. *Oil Treated*: The procedure followed in oil treating consists of annealing, machining, quenching and drawing. In this case, oil is used for the quenching bath. The physical prop-

Fig. 16. Case-Hardened Tooth, Broken to show Refinement of Structure of Case and Toughened Core.

erties shown in Table 1 for oil treated medium carbon and for oil treated high carbon steel have been found to give good results in service. A photograph of the structure of an oil treated pinion tooth is shown in Fig. 14.

3. *Case Hardened*: The procedure followed in case hardening consists of annealing, machining, carbonizing, quenching and drawing. The carbonizing is usually done by packing the parts in cast iron boxes entirely surrounded with carbonizing material, the boxes are sealed, charged into a furnace and brought

gradually to a temperature that will volatilize the carbonizing compound, giving off a gas rich in carbon and at the same time transforming the structure of the steel into a condition that absorbs the free carbon. After the heat is shut off, the pot should be allowed to cool slowly in the furnace, then removed and dumped. The gear may now be annealed to refine the grain which may have been made coarse by the high carbonizing heat. The gear is then given a single or double quench in brine, or in oil and brine, the oil quench being given to refine the core and the brine quench to refine the case. A broken tooth, polished and etched to show depth of case, is shown in Fig. 15; and a tooth broken to show refinement of structure of case and toughness of case is shown in Fig. 16.

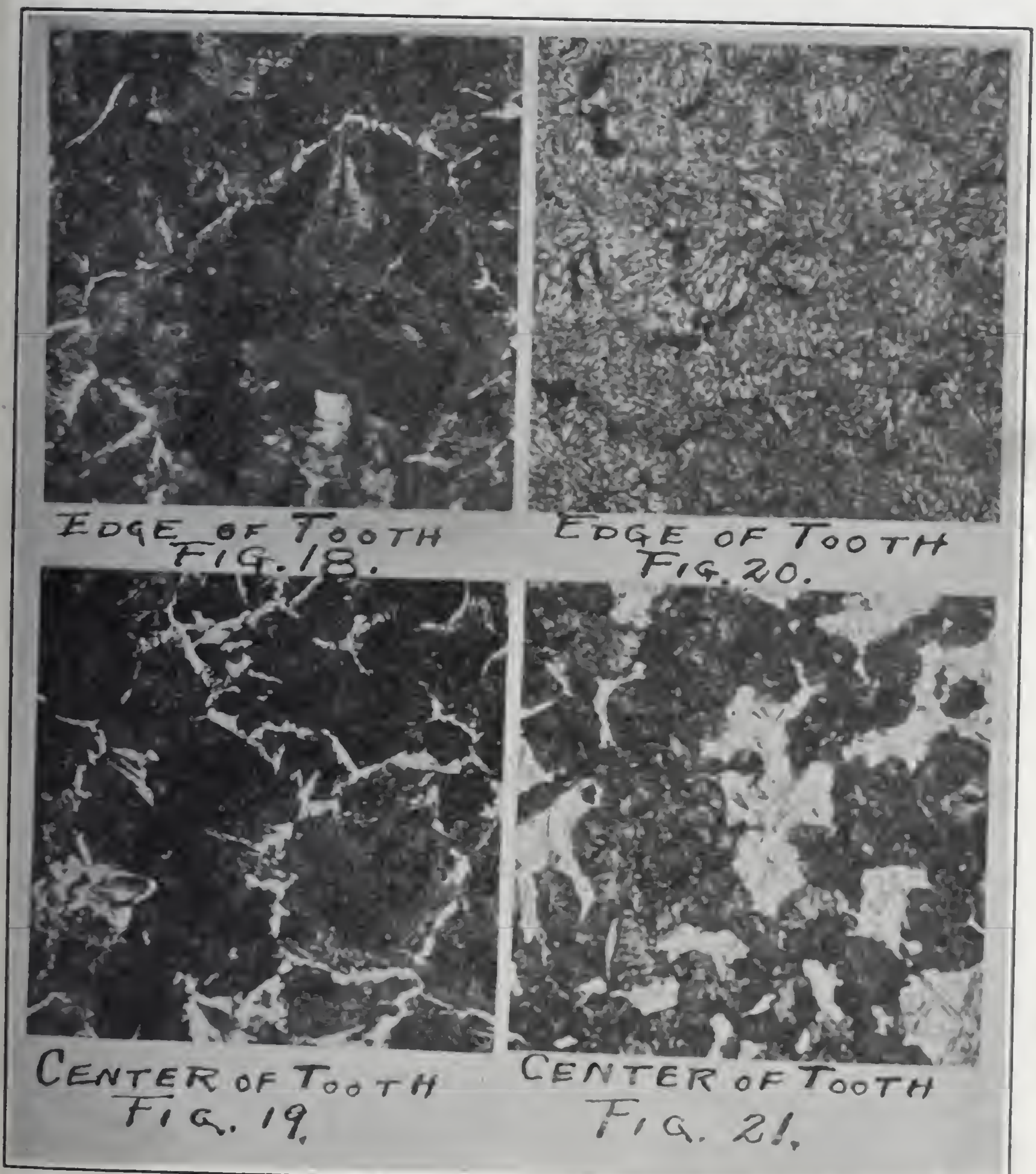
Fig. 17. "B. P." Process Tooth Broken to show Refinement of Structure.

The depth of carbonization required is determined by the size of the tooth and permissible wear of same in service. This is controlled by the time and temperature of the charge in the furnace, and to a limited extent by the composition of the steel as, for example, it is asserted that nickel and silicon retard, while manganese and chromium accelerate penetration.

There is a gradual transition from the extreme hardness at the surface of a case hardened gear to the tough, ductile material at the core. The surface may have a scleroscope hardness of approximately 85 to 95.

4. *B. P. Process*: The *B. P.* process consists of the following sequence of operations—annealing, machining, quenching and drawing. The careful selection of the raw material and the quenching operation constitute the main features of the high qualities of this product. It is well known that many of the

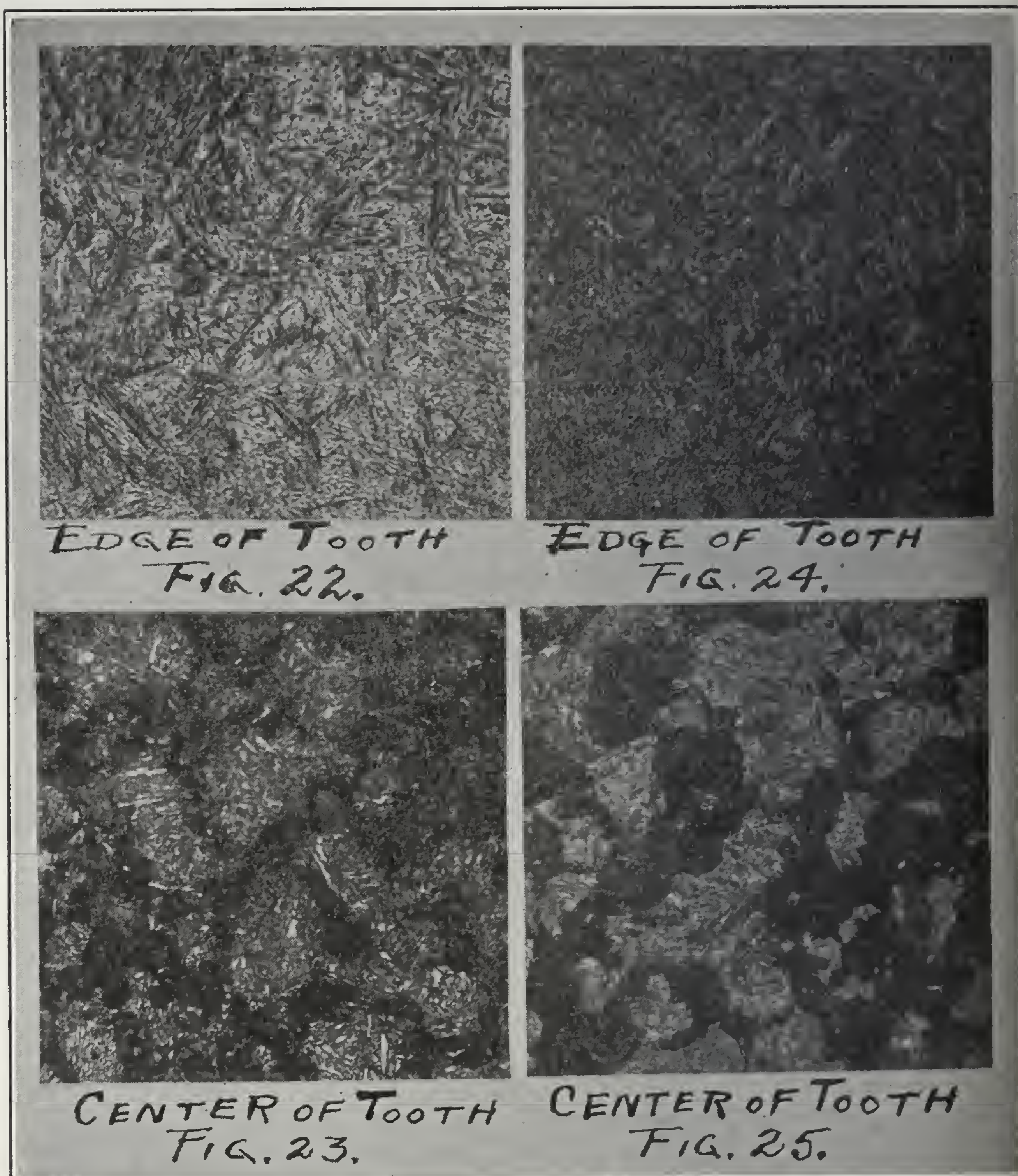
existing drastic treatments of carbon steel tend to produce a very hard material with a high tensile strength, but at the sacrifice of ductibility. The *B. P.* process, however, produces a very hard material with a high tensile strength and retains its ductility. The hardness tapers gradually from the wearing surface to the center of the tooth as shown in Fig. 17. The physical properties of this material are shown in Table No. 1.



Figs. 18 and 19. Micro-photographs of Tooth Structure, Oil Hardened, Quenched only.

Figs. 20 and 21. Micro-photographs of Tooth Structure, Water Hardened, Quenched only.

To compare the more highly refined structure of the *B. P.* process with that of other treatments, micro-photographs of oil hardened teeth (Figs. 18 and 19) and of water hardened teeth (Figs. 20 and 21) are introduced. They are all from the same bar as Figs. 22, 23, 24 and 25 of the *B.P.* process. A close examination will demonstrate the difference in grain structure.



Figs. 22 and 23. Micro-photographs of Tooth Structure, "B. P." Process, Quenched only.

Figs. 24 and 25. Micro-photographs of Tooth Structure, "B. P." Process, Quenched and Drawn.

EQUIPMENT

The furnace should be of the semi-muffle type, the flame not being allowed to impinge on the steel. There should be an air chamber under the floor of the furnace to which heat has free access. The furnace should be so arranged that the hot metal can be quickly transferred from the furnace to the quenching bath and should be equipped with pyrometers capable of

Fig. 26. Brinell Hardness Machine.

reading accurately to 2000 deg. Fahr. The quenching bath should be sufficiently large to absorb all of the heat of one furnace charge and still maintain the temperature of the bath within a range that will not materially affect the results. A refrigerating system should be used to reduce the temperature of the bath for subsequent furnace charges. The bath may be oil, water, brine or any liquid solution that will give the desired results as indicated by experience.

HARDNESS TESTING MACHINES

In order to insure uniformity of results some physical test must be made on each piece of steel treated. This test in order not to destroy the piece must be a surface test. There are two

forms of surface testing machines, the Brinell and the Scleroscope.

Brinell Machine: The Brinell machine shown in Fig. 26, tests the hardness by pressing a 10 millimeter ball into the surface of the steel at a pressure of 3000 kilogrammes. The diameter of this impression is measured by a microscope to within 1-20 of a millimeter. The reading is only relative as is all hardness, but by many tests on different steels of known physical properties, tables of equivalent physical properties have been worked out and are fairly accurate.

Fig. 27. Shore Scleroscope.

Scleroscope: The scleroscope, shown in Fig. 27, tests the surface hardness of a steel by dropping a diamond pointed hammer from a given distance upon a polished surface of the piece to be tested and noting the height of rebound of the hammer. It is claimed by Mr. Shore, the inventor, that a pressure equivalent to 487 000 lb. per sq. in., is obtained when the hammer, which is 1-25000 sq. in. area at the point, strikes the material under test. The scleroscope detects surface hardness while the Brinell detects hardness to considerable depth.

TESTS

All tests should be made after the gear or pinion has been treated in full action. Tensile tests should be made from a

sample taken at the root of a tooth of a pinion parallel to the face of the pinion and either at the side of the face of a gear or gear rim tangential to the face, or at the root of the tooth parallel to the face of the gear. Brinell tests should be made on the end of the teeth of all finished gears, gear rims and pinions, except case hardened gears, which should be tested with the scleroscope.

We have given a brief outline of the development of railway gearing to date. Further developments must follow so that the gearing will maintain the proper relation with the other parts of the equipment, which are continually tending to grow to meet the demand for increased capacity.

Cooperation in the fullest measure between the steel maker, the forging company, the gear manufacturer and the railway operator, is the prime essential for satisfactory development.

DISCUSSION.

Mr. A. Stucki: I suppose the *B.P.* process is a secret process and that there is no information available in regard to it.

Mr. T. D. Lynch*: Yes. It is a secret process, the details of which we are not privileged to discuss.

Mr. G. F. Hinkens: I would like to ask a question for information. Suppose we take a different alloy with a different carbon, is there any way to determine the point of transformation or the point of recalescence, or the critical point? Can any one determine that without an instrument?

Mr. T. D. Lynch: I do not think anyone would attempt to do very careful heat treatment without an instrument to measure the temperature.

Mr. G. F. Hinkens: You do not understand my question. What heat shall we use for different kinds of steel in order to bring out the proper heat treatment?

Mr. W. L. Allen†: The gentleman's question regarding the manner in which the critical ranges of steel may be determined might be answered in this way:

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†Commercial Engineer, R. D. Nuttall Company, Pittsburgh.

The critical range of steel varies with the carbon content. As brought out in Mr. Phillips' paper, the temperature to which steel should be heated for quenching, is not necessarily an exact temperature, but slight variations from this temperature will not materially affect the result. By that I mean, that providing the steel is heated above its upper calescence point, and cooled below its lower recalescence point, the resultant product will be hardened. It is, however, not advisable to heat steel any higher above the upper calescence point than is necessary to bring about the desired hardness, as any increase in the temperature to which the material is heated over the calescence point, while not materially increasing the resultant hardness, has the effect of coarsening the grain structure.

A great many technical writings have been gotten out within the last few years in which the critical ranges for variable analyses of steels may be obtained, one of which is a book recently published by Mr. Sauvier on the *Metallography of Steel.*

In Mr. Phillips' absence I feel that I should take the liberty of bringing out a point which I am sure he would have brought out had he been here, namely, that the paper which he has prepared, while dealing with gearing in general, has particular reference to the heat treatment of railway motor gearing.

As pointed out by Mr. Phillips, the development of the railway motor has been such as to continually increase the demands on railway motor gearing and it has, therefore, been our aim to produce a material which will meet these demands, not only from the standpoint of strength, but from the standpoint of ultimate economy.

With this aim in view the general experiments along the lines of improving railway motor gearing were conducted through the oil tempering of the medium carbon steel, then being used in the normal condition. While through this oil tempering a very much more efficient gearing was produced then was true with the untreated or normal stock, the increase in the strength and resultant life brought about through this oil tempering in no way equals the results which have since been produced through case hardening or the application of the *B.P.* process, either from the standpoint of life or from the standpoint of the safety factor.

The *B.P.* process, of which the gentleman to the right asked, was the outcome of years of research on the part of the Nuttall Company aiming to produce a gearing having high surface hardness combined with great strength and refinement of structure, at less cost than is possible through case hardening. Case hardening of railway motor gearing is very costly on account of the fact that after machining it must be carbonized for several hours and then heat treated. This heat treatment sometimes requires two or even three heatings to produce the desired results.

The *B. P.* process does not develope as efficient a gearing as is brought about through case hardening, but the efficiency which is produced in this process very closely approaches that of the case hardened material and at so much less cost as to make the *B.P.* grade of gearing very much more economical for the average present day normal operative service.

Efficiency in railway motor gearing to which I refer is not so much mechanical efficiency as the mechanical efficiency combined with long life.

There is a certain variation in mechanical efficiency in gearing brought about through heat treatment on account of the tendency of this gearing to warp in heat treatment. The amount of this warping will depend upon the method employed and the accuracy of the heat treatment, and while the mechanical efficiency varies somewhat with the amount of this warping, the efficiency of which I spoke was with particular reference to the elimination of breakage, and the ultimate life of the gearing.

The *B. P.* process is such as to produce a material having not only high surface hardness, but combining with this hardness great strength and ductility as well as good refinement of grain, resulting in the development of almost as much mileage as can be obtained from case hardened gearing without any breakage, and at the same time with very good economy.

Mr. S. M. Rodgers:* Not being familiar with the manufacture of gears, I am not competent to discuss this paper. However, there is one point brought out with reference to the manufacture of gear blanks about which I would like to ask

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a question. How much better is a gear made out of a blank that has been upset than one of the same size and character that has been made from a forging which had not been upset? In other words, does the work of upsetting from a smaller diameter to a considerably larger cross section materially improve the strength and durability of the gear? I understand it is a common practice to make several sizes of blanks from a forging of the same diameter by using different lengths, and it would be interesting to know what experiments have been conducted to show that the gears made from the upset blanks are superior to those made from blanks that have only been forged in one direction.

Mr. W. L. Allen: The Nuttall Company have made a great many experiments to determine the relative merits of pinions cut off forged or rolled bars, as compared with pinions made from individually forged or pressed blanks, and have found that in some cases an individually forged blank produces a stronger and better pinion than those made from blanks machined from bars.

While it is generally conceded that an upset structure is not as good as the structure of a material which has been worked in one direction only, the direction in which the load is applied to pinions is such that in the pinions made from bars this load application is transverse to the grain of the steel, while in the individually forged blanks the condition of the grain is changed through the upsetting.

Mr. G. F. Hinkens: Do I understand that the forged blank is poorer in construction on the outside diameter, i.e., on the edge? I would consider the center of the blank the better for the reason that the structure or particles are held more intact by the outer support. The outer or edge portion in forging yields more easily, the metal not flowing in a straight line but radially, exerting a tearing stress on the edge, causing checks or openings on the rim or edge of the forging. You will find these conditions very pronounced in wrot iron, or the poorer grades of steel.

The soundness of the circular blank will converge towards the center, when upsetting a billet from a smaller diameter.

Mr. W. L. Allen: I believe that I can safely say that a material made by hammered forging has higher physical properties and denser structure near the surface than it has at the center, and that this condition also exists to a more or less extent in the rolled bar, depending somewhat upon the manner in which it is rolled. In press forging, however, it is my opinion that the material is compressed at the center more than is true either in hammering or in rolling, and the result is the producing of a more homogeneous mass throughout than in the hammer forged or hot rolled.

Mr. A. Stucki: You have mentioned the difference in grain resulting from forging and pressing. If we have a piece of rolled material and forge it by a number of strokes into another shape, what is the difference in structure compared with doing that same work with one stroke under a press?

Mr. T. D. Lynch: I do not know that I can answer that question fully. However, there is no doubt that a piece of steel forged under the press is tougher and has a better grain than when forged under the hammer. The press gives the metal time to flow while the hammer strikes suddenly and has a tendency to break up the tough grain formation. Tests that have been made to compare hammer forged with press forged steel show very clearly, even in the same piece of steel, that a better and tougher grain is produced by press than by hammer forging.

Mr. G. M. Eaton:* One of the possible advantages of upsetting a pinion blank is the development of any possible existing seam, which is one of the things that has to be contended with in steel. In other words, the upsetting is an excellent inspection operation by which a certain amount of defective material will be eliminated before it goes into service, and material in which the defect would be detected in no other way.

Successful heat treating is not simply a function of arriving at a desired temperature, and then arriving at another desired lower temperature. It involves a heat cycle, for example, putting the cold material into a furnace whose temperature is sufficiently low so that the mechanical strain of the first heat

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is low enough to avoid inducing tensile strains causing internal cracks. The same is true at every stage of the operation, both in annealing and heat treating. Heat treating is a cut and try operation, and the temperatures given by the steel maker, unless he is intimately acquainted with the exact results to be obtained, will not necessarily produce what is desired. Each concrete problem demands its own specific solution.

The problem that I appreciate most strongly has already been touched on, namely, the increasing of the demands put upon railway motors. There is not a gear in the market that is good enough for certain drastic services. One operator, connected with a large city system, says that if gold were the material best adapted physically for pinions, he could afford to pay the price.

Heat treating with a raw material that is not ideal is building a super-structure on an uncertain foundation. No matter how good steel may be, it ought to be better. We want to make motors bigger and more powerful. We are absolutely limited to a certain gauge. The most tempting change in the motor is to make the armature longer. After a design is laid out, we hunt it over for a quarter of an inch, and we tackle it later for an eighth and we work it down to a sixty-fourth. We make a gear 5¼ in. wide. We would like to make it 3 in. wide, which would make the gear do approximately twice as much per unit width. If the gear lasts ten years it is a poor investment if it is paid for by an excessive amount of copper in the armature. Nobody wants to buy a cubic inch of steel and pay a cubic inch of copper for it.

I have talked with men who make electric steel. I understand the presence of oxides in steel is one of the menaces that are met in heat treatment. We are told that they can be eliminated in the electric steel, except such oxides as occur in pouring from the furnace. Isn't that promising? Isn't electrical steel going to come into its own some day soon? Electric steel applies just as much to the forged type of gear as to cast gears.

One word as to flexible gearing: This was first designed and applied practically to commercial use by the W. E. & M. Co. in large locomotives where there was a pinion on both ends of

the armature shaft. It was felt that it would be exceedingly difficult to secure the two gears on the end of the gear shaft and align them with such accuracy that the pinions would divide the load equally. Therefore, the rim of the gear was made flexible relative to the center of the gear so that an approximately equal distribution of the load would be achieved. I happened to see an installation in which flexible gears were used. One locomotive had run 90 000 miles. The next day in a similar installation, except that the gear and pinion were rigid, the locomotive had run but 16 000 miles. I looked the records up pretty carefully because I thought I had the figures just reversed. The condition of the gearing on the locomotive at 90 000 miles with flexible gears was vastly better than that on the locomotive at 16 000 miles with solid gears.

The next step was to apply these flexible gears to motor cars. The photographs shown in the paper represent the result of a long development. All the surfaces, where movement occurs between two contacting pieces of steel, are case hardened and ground. I saw the first gears of this type after they had run 15 000 miles. No wear could be detected with micrometers. They were opened later at 60 000 miles and the same results were recorded. The advantage of the flexible gear in motor cars is very far-reaching. When a railway vehicle is running at very high speed, and particularly when the track is relatively rough, the rail ends, frogs, etc., impose heavy shocks, not only upon the rotating parts of the motor, but also upon the brushholders, the truck frame, and the car body, etc. The flexible gear was designed to dampen out the dynamic peaks, and it demonstrates in service that it fulfills the purpose.

Mr. James O. Handy*: I cannot add anything to the discussion about heat treatment of gears. The results of defective heat treatment of other materials may be of interest.

Railway car axles and locomotive axles which had been treated in a supposedly correct manner gave very unsatisfactory results. In one case a new locomotive axle, when it was being unloaded, broke when it struck the railroad platform. In another case, some new heat-treated car axles broke in the trial

*Research Director, Pittsburgh Testing Laboratory, Pittsburgh.

of the finished cars in the yard. The cases were afterward carefully studied and we became convinced that the defect was the uneven heating in the furnace and the uneven rate of immersion in the quenching bath. Too many axles were put into the bath at the same time so that they were not all uniformly cooled.

Heat treatment, as we all know, is a very delicate operation. Results, if the work is well done, are very fine, but if the operation has not been carried out with accuracy, the heat-treated articles may be less reliable than they were before treatment.

MR. S. A. GRAYSON:† Mr. Lynch has spoken about the effect of manganese on the steel. I have found the fundamental factor in heat treatment is the manganese in the steel. After all heat treatment is a means to an end, a means of producing a structure the tensile strength of which is high enough to stand the requirements of the service, and manganese has been a very fortunate thing in obtaining that. Mr. Lynch had a slide showing the carbon but none showing the manganese. In the case of steels for gears it is of very much more importance than the average person is inclined to imagine. One of the reasons is on account of the expansion and contraction. Manganese steel is not susceptible of excessive expansion, therefore relative proportions of manganese increase or decrease the effect on the surfaces, and in obtaining the recalescence curve that is a point on which a great deal of stress should be paid.

A MEMBER: I would like to ask Mr. Allen if there have been any experiments made concerning the use of high manganese steel and case hardening some teeth.

MR. W. L. ALLEN: Do I understand from your question that you refer to the high manganese steel having 12 or 14 percent manganese, or a steel having approximately 1 percent manganese?

A MEMBER: About 14 percent.

MR. W. L. ALLEN: I personally have not conducted any experiments along the lines to which you refer, nor have I any knowledge of any similar experiments having been conducted,

†General Manager, Jessop Steel Company, Washington, Pa.

but off hand it occurs to me that the commercial phase of this situation would be very important in the manufacture of gearing in such a way, on account of the fact that even with the present analysis of manganese steel, it is impossible to machine or cut the teeth in the pinion or gear blanks, but the contour of the teeth must be obtained in casting and trued up by grinding. This grinding is very expensive, and is generally thought to be inefficient, and as the results which have been obtained from manganese steel for gearing purposes have not proven very successful as yet, I very much question whether the additional expense brought about through carbonizing would be warranted.

Mr. A. Stucki: When the last gentleman was speaking about fatigue it brought to mind the properties of vanadium, as we all know that this element makes steel especially able to resist dynamic effects. I would like to know to what extent vanadium has been tried and what the results have been. I am quite sure that the alloy would help out in the direction of fatigue especially.

Mr. W. L. Allen: We have done more or less experimenting with chrome vanadium steel for gearing, and are at the present time carrying on some experiments with the manganese vanadium steel, which is entirely free from chrome, having a manganese content of about 1¼ to 1½ percent. These experiments have been carried on both in the case hardening of this material as well as the oil tempering, and water quenching, but so far as I know there have been no tests carried far enough as yet for us to determine what the ultimate results will be, on account of the fact that our present standard products wherein carbon steel heat treated is used, may even in the most severe service last several years and it is therefore, impracticable for us to obtain any dependable data on test gears or pinions in much less than a year or two, and as the chrome vanadium steel has not yet been in service for this length of time, so far as I know, we are unable to express an opinion as to its merits as yet.

In the use of chrome vanadium steel or any alloy steels in the manufacture of gearing, it is necessary to take into consideration the fact that on account of the complicated contour of

the gear there is a great tendency for this section to crack in the heat treatment, and the greater the number of alloys added to the steel, the greater the complications set up in heat treatment and correspondingly an increase in the tendency to crack. We do not feel that the heat treatment of carbon steel has as yet been developed to the highest degree of efficiency, and from the present results which we are obtaining from such materials as *B.P.* process and case hardening gearing in the present day service, we are inclined to feel that we should exhaust our researches in the heat treatment of carbon steel before going too deeply into the use of the higher priced alloy steels such as chrome vanadium.

MR. A. STUCKI: You have no data then in regard to manganese and vanadium steel at this time?

MR. W. L. ALLEN: We have made a great many laboratory tests in which the resistance to alternating stress has been observed as well as other physical characteristics of gearing, but the actual service tests have as yet not been completed, and present indications are that it is a matter of not less than one or two years.

MR. R. A. MCDONALD:* The doors of this discussion seem to have been thrown pretty wide open. Heat treatment of steel is not new. We have heard a great deal about it recently. Originally it was only iron and the method of making steel was simply the old cementation process. It has largely extended from that, Bessemer, open hearth, crucible and electric. The largest object that is treated is armor plate, which is treated by several methods, Krupp, Harveyized, etc.

Gears for automobile use, sizes considered, receive more severe treatment in service than any other, but they do not use straight carbon steel as a rule for these gears. They have gone to various alloys, nickel, chrome, tungsten, vanadium, etc. There isn't any real vanadium steel that amounts to much for gears, alloyed with other elements, either nickel or chromium or tungsten, adds to the life. Vanadium does add virtues to it but its best virtue is in the addition of some other element besides simply the vanadium to the automobile steel.

*Manager, Crescent Works, Crucible Steel Company of America, Pittsburgh.

Dr. J. S. Unger:† The treatment of gears is something that metallurgists have studied for a long time.

A process was brought out several years ago to harden the tooth of a cast steel gear by coating the inside of the mould with powdered ferro manganese. When cast, the temperature of the molten steel was high enough to form an alloy at the surface, giving what might be called a manganese steel, which did not wear away rapidly. Another process was brought out in which ferro chromium was substituted for ferro manganese.

These teeth were very rough, sometimes full of holes, and usually so hard it was impossible to machine them. When a gear of this kind was put in service where sudden reversals or heavy starting loads were common, the hard alloyed surface would sometimes shell off, causing trouble.

At one time we experimented with a ferro manganese gear in contact with two ordinary cast steel gears. The manganese gear did outlast the others three to one. While it showed very little wear, it wore out the softer gears from two to three times as fast as they would have worn had the three gears in contact been of the softer material. We simply transferred the wear from one to the other gear.

The question of heat treating gears was primarily brought about for this reason: The trade required a gear that would wear longer that the ordinary gear. The ordinary gear tooth would wear away until it was not strong enough to resist the force, then it would break at the point or at the root. In addition to securing a hard surface which would wear better, the aim was to make it stronger at its root, so it would not break off under sudden strain. The heat treatment increased the strength, without reducing the toughness to any great extent.

Case hardening a gear tooth has two advantages. The depth of the penetration of the carbon can be easily controlled, and there is no sharp line of demarcation, but a gradual merging of the hard into the soft steel, producing a tooth admirably adapted to resist wear.

Mr. W. R. Wigley: May I say a word about the resistance of steel to fatigue and the effect of heat treatment upon that resistance? What I have to say is based upon some recent labo-

†Manager, Central Research Laboratory, Carnegie Steel Company, Duquesne, Pa.

ratory experiments and I think that some of the things that were developed are new.

Four grades of carbon steel were used in making the tests. The carbon content of the first series of test pieces was about 0.14 percent; of the second series about 0.32 percent; of the third series about 0.60 percent, and of the fourth series about 1.02 percent.

The pieces were tested by bending them back and forth thus setting up transverse stresses in the material. Each piece of a series was bent through a definite angle and the bending continued until rupture took place. For each piece the bending stress was computed and the number of cycles of bending back and forth was counted. By changing the amount of bend in the various pieces of a series, it was possible to determine the life of the material (in number of cycles) at various stresses.

In plotting the results a special plot was used. The ordinates were $\log_{10}$ of the stress, and the abscissae were $\log_{10}$ of the number of cycles. The curves were of about the shape shown in Fig. 28.

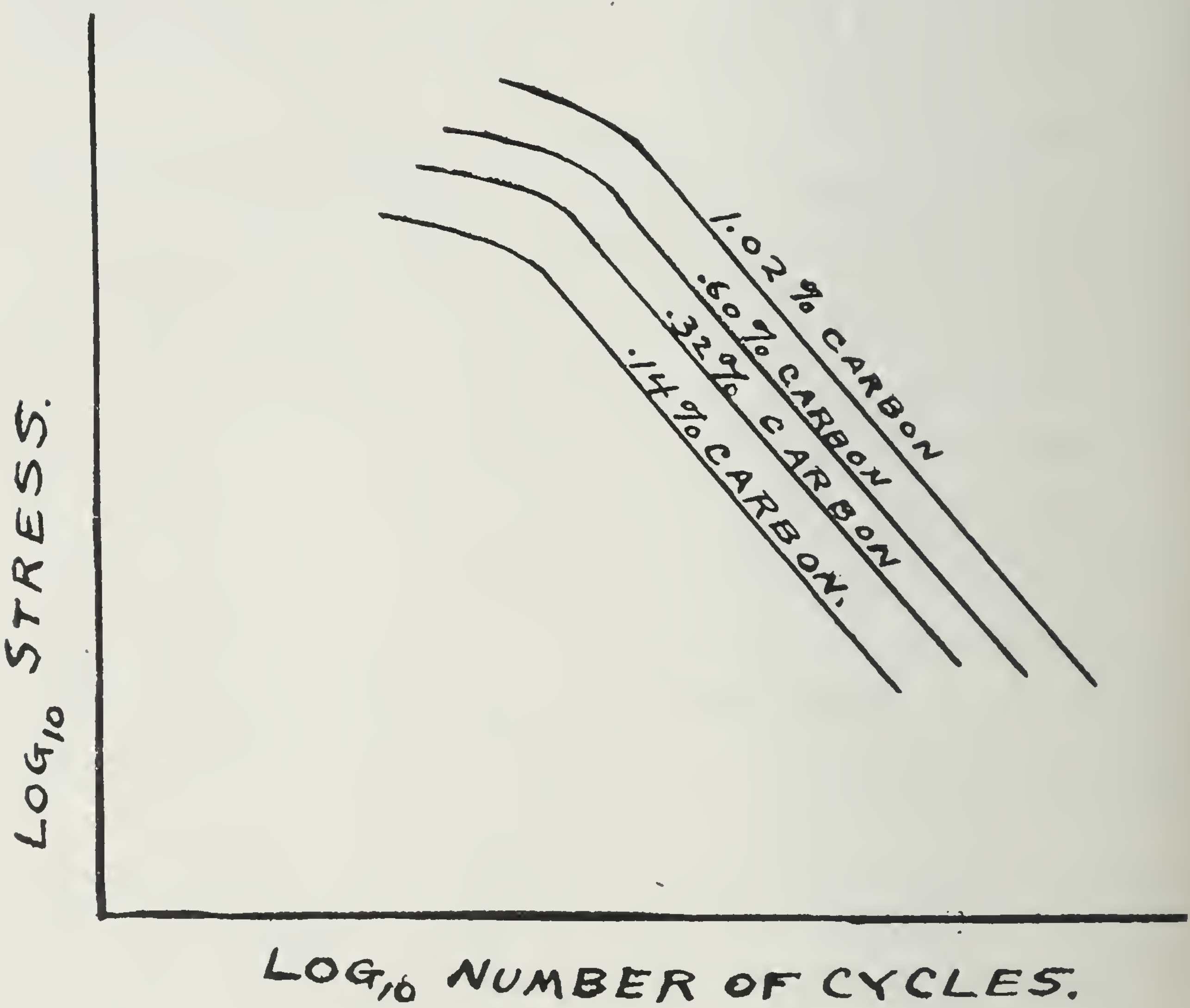

Fig. 28.

If curves had been plotted stress vs. number of cycles without using the logarithmic scale, a series of hyperbolas would have resulted and it would have been very difficult to detect discrepancies in the results of tests.

From these curves, it is evident that at any stress the higher carbon steels withstood the repeated stresses better than the lower carbon steels. In these tests the loads were applied without impact. Impact might change the relations to some extent.

One of the things, upset by these experiments, was the belief in a natural elastic limit. The tests seemed to indicate that there is no such thing as a natural elastic limit, at stresses below which a steel will have infinite life against repetitions of load. Another factor was brought out and that is, that rest will prolong the life of steel to some extent.

With regard to heat treatment. In this same laboratory various heat treatments were practiced on these four grades of steel and the heat treated pieces were tested against the normal steels. One heat treatment was developed with one of the steels which gave the steel the same life as the normal one but with the stresses about three times greater in the heat treated piece. What the comparison might have been in length of life, had both the normal and heat treated pieces been tested at the *same stress,* is a matter for speculation. Undoubtedly the heat treated piece would have had a much longer life. The structure of the heat treated steel appeared to be troostitic upon inspection. No microscopic examination was made. This troostitic (apparently) structure seemed to give better results than any other structures we were able to develop by the heat treatment given to the four steels.

MR. H. P. TIEMANN*: Mr. Lynch spoke of the effect of heat treatment on the elastic limit. Back in the early thirties of the last century Wöhler showed the effect of repeated stresses on steel causing failures, and he showed that if the stresses were below the elastic limit and sufficiently close to it, a certain number of stresses would cause the material to break down. The nearer the stress to the elastic limit, the more quickly the material would break down. If it were considerably below it. a

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very great number of alterations of stress would be required, until finally a point (which has been termed the natural elastic limit) is reached, below which an infinite number of stresses could apparently be applied without causing failure. I think one reason Mr. Lynch made the statement that the advances in gears had been greater in the last decade than in any other time, was due to the fact that heat treatment can affect the elastic limit to a greater degree than the other properties, and it seems to be the elastic limit which determines primarily the life and strength of a gear.

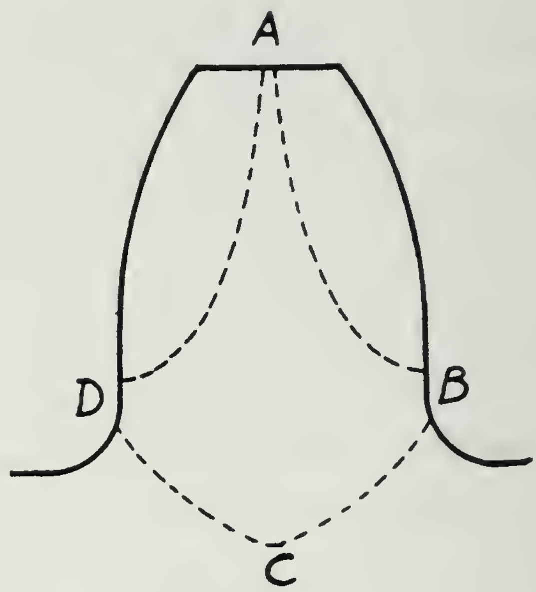


Fig. 29.

The failure of gear teeth, when not caused by excessive brittleness or shock, is due to a detailed fracture, *D C B,* Fig. 29, where repeated alternate stresses too nearly approach the elastic limit. Detailed fractures for all classes of material have been and, to a more limited extent, still are attributed to the material being too brittle. If, however, the logical correction, based on such premises, is made the material will be found to fail even more rapidly. This is due, as already explained, to the decrease in the elastic limit.

In Fig. 29 the dotted lines *D A B* show the final contour of the tooth which may result from the wearing action. Here, failure does not usually occur by bending, unless a sudden excessive load is applied, but by detailed fracture along the line *D C B.*

I believe that the modulus of elasticity must be taken into consideration in the design of various classes of material sub-

jected to repeated stresses or shocks, to provide a section sufficient in size to avoid excessive flexure. If the modulus of elasticity has the importance which I ascribe to it, it will be appreciated that as it is practically constant for all grades or types of steels, the substitution of steel with higher properties might not be sufficient to correct trouble from breakage unless it were known that the section were ample. In other words, there would be a critical size or section below which all grades of material would give trouble. Both these improvements in the physical properties of the material would have a corresponding effect upon the life or service of the object.

It might be well here to call attention to a distinction which is not always appreciated, that is, between the object as a whole and the material of which the object is composed. The material may be of the very best quality, but unless the object is properly designed, failures may occur. For example, treatment might result in setting up such strains that cracks or even total rupture would be occasioned. The object would thereby be destroyed, while the material itself upon suitable investigation would be proved to be of entirely satisfactory quality. If an attempt were made to erect a structure employing the highest grades of materials, but no method of fastening the various pieces together were employed, the structure would fall, but blame for this could not attach to the component materials.

In practically all experiments which have furnished the information we at present possess, relatively very small pieces were employed. It is possible to heat or cool such pieces nearly uniformly throughout, about as rapidly as desired. When, however, the attempt is made to put into practice the principles so obtained, it is found that a new factor enters largely into the problem, namely, the mass of the object treated. For example, if a piece of fine wire is heated and then exposed to air at the ordinary temperature, it will be cooled almost instantaneously, while the time required in the case of a large shaft, even when plunged into cold water, will be many minutes.

Under similar conditions the rate of heating and cooling is much less for a large than for a small section, for two reasons:

First, because the distance to be traversed between the surface and the center, in the absorption or dissipation of heat, is greater. This rate progressively decreases as the temperature of the body, or of one portion of the body in relation to another portion, approaches that of the source of heat or refrigeration, in accordance with one of the fundamental laws of thermodynamics.

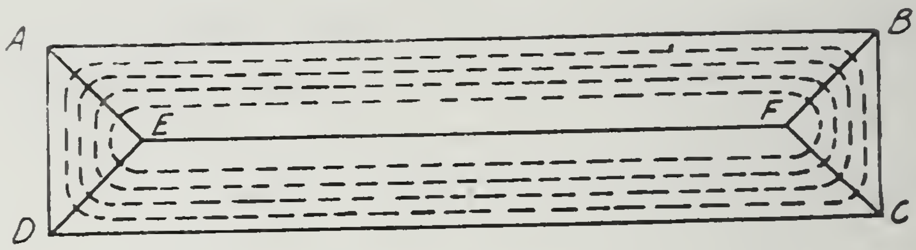


Fig. 30. Manner of Transmission of Heat.

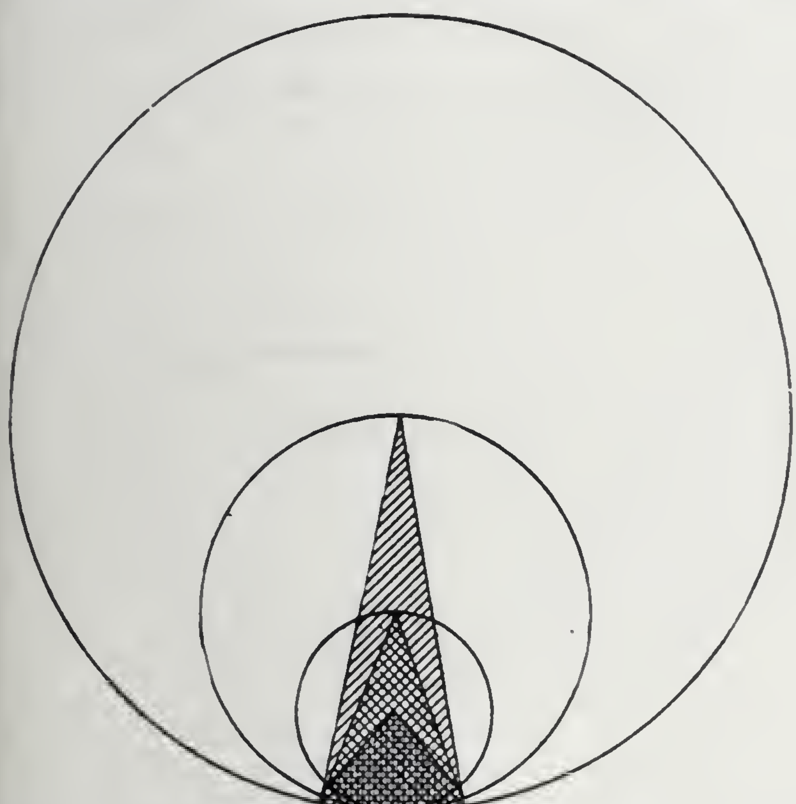
Fig. 30 is intended to illustrate how the transference of heat occurs between different portions of the surface and the interior. *A B C D* is a section through an object uniformly heated or cooled on all sides. The transference of heat to *A B F E* is through *A B*; to *A E D* through *A D*, etc. The progressive effect is indicated by the dotted lines which are rounded at the corners of the section, because in those regions it is obtained from two sides.

Second, because the cross-section increases directly as the square of the diameter, while the circumference increases only in simple proportion to the diameter. The same relation also exists between surface and volume (mass), since these are obtained by multiplying the circumference (or perimeter) and the area, respectively, by the same value representing the length.

In Fig. 31 is a table of ratios between circumference and area for circles of diameters of *1* to *10*. In the same figure are shown three circles with diameters of *1*, *2* and *4*. The hatched portions show graphically that the same linear distance on the circumference of each must serve for the transfer of amounts of heat which are respectively *1*, *2* and *4*; as already explained these ratios are the same if the surfaces and volumes (masses) are substituted. This may be summarized in the general law that for bodies of similar section the amount of heat transfer-

red per unit of surface is directly proportional to the ratios of their diameters (or similar dimensions of their cross-section).

The preservation in the cold state of the condition which existed at the temperature to which an object is heated (above the critical point) is dependent upon a certain rate of cooling, irrespective of the size or mass of that object. With the means at our command it will readily be appreciated that a point is very quickly reached when no method of cooling can compensate for the increase in mass, so that the rate of cooling decreases with corresponding increase in the actual time required.



Diameter of Circle	Relative Circum.	Relative Areas	Ratio Area to Circum.
1	1	1	1
2	2	4	2
3	3	9	3
4	4	16	4
5	5	25	5
6	6	36	6
7	7	49	7
8	8	64	8
9	9	81	9
10	10	100	10

Fig. 31. Relative Amounts of Heat Transmitted per Unit of Area of Surface.

As a direct result the interior of large masses will be cooled so slowly as to have only the properties of smaller masses cooled in the same time, or, in other words, the effect has been that of annealing rather than of quenching, as these terms are commonly understood. The exterior portion, although considerably retarded in its cooling by the necessary transfer through it of heat from the interior will be benefitted in proportion to the rate at which its temperature was brought below the critical range, the properties of different portions of such a piece being in inverse proportion to the distance from the surface.

Fig. 32 is intended to show this state of affairs graphically, but without any claim as to its quantitative or even its qualitative accuracy. The curve *A B* is supposed to represent the maximum theoretical relation between strength and ductility for steel of any given composition; steels of other composition would be represented by curves varying progressively from one another. If it be tentatively admitted that this curve is correct, then a piece with the properties corresponding to the point *A*, with relatively high strength and low ductility, would be of equal merit with another piece with properties *B*, where relatively low strength is combined with high ductility; or with a piece with properties represented by any other point on the curve, since the curve is drawn on the assumption of a constant value for the relation between strength and ductility.

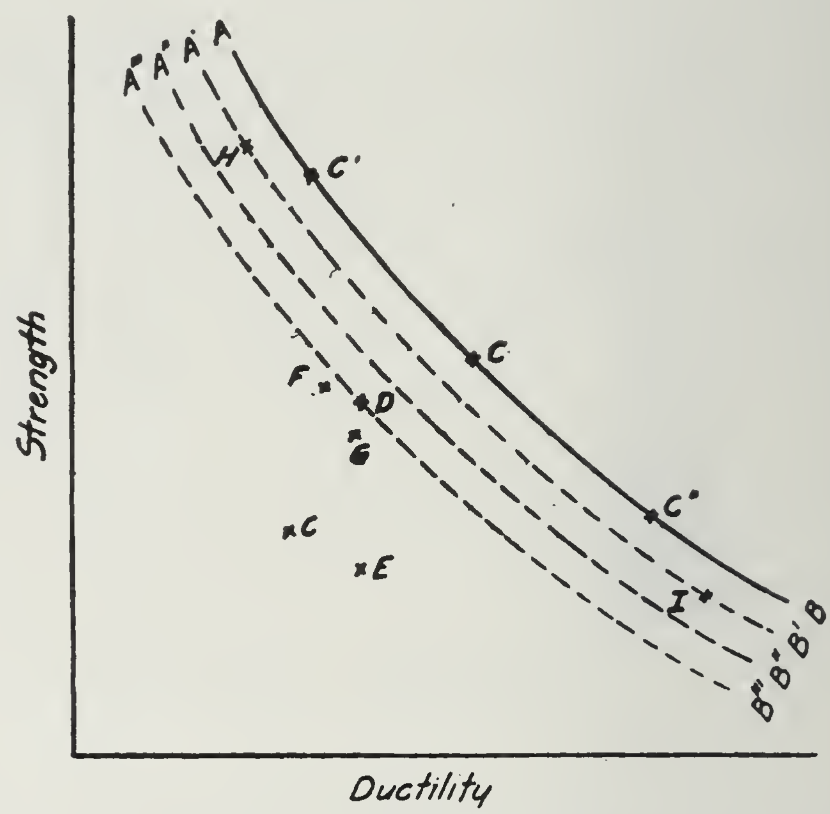


Fig. 32. Diagram Showing Effect of Mass.

If a piece had only the properties *C*, the strength, according to our assumption, could be increased to *C'*, the ductility remaining the same; or the ductility could be increased to *C''*, the strength remaining the same; or any other maximum relation could be attained, as *C'''*, on the curve *A B*.

In actual practice or experiment, however, the factor of mass is bound to enter in, even with the smallest obtainable

section, so that this maximum curve can only be approached but never quite reached. With very small pieces the experimental maximum might be as represented by the curve A', B'; other curves A'', B'', A''', B''', etc., would, in the same manner, represent the possible maxima which could be attained by pieces of increasing section.

If the point C, for example, represents the properties of a large untreated section, these could probably be improved by annealing to some point E, or by quenching and tempering F or G. With cooling more rapid than usual, as by quenching in iced brine or liquid air, followed by tempering, the point D might be reached.

The reason for the higher relation of properties in a small section over that in a large section, treated under the same conditions, would appear to be due principally to the condition of the carbon. This is also borne out by the difference in the properties of test specimens cut respectively from near the surface and at the center of large sections, which has resulted in the clause in forging specifications that "the axis of the specimen shall be located at any point one-half the distance from the center to the surface and shall be parallel to the axis of the object tested," with a view to determining the average values.

Under suitable conditions of heating it is possible to secure a reasonably uniform temperature throughout a fairly large section. If the rate of cooling could then be controlled so that a large section could be cooled as rapidly (that is, in the same time) as a smaller object, the uniformity of the material in the two cases should be the same. As a matter of fact, however, such a state of affairs cannot be attained, as the conduction of heat from the center to the outside of a section of any size is relatively slow for the reason already given, and cannot be hastened sufficiently by any means at our command. Even if such were not the case, there is another insurmountable obstacle in the path. This is the possible introduction of excessive strains in large pieces, particularly where there is any irregularity of section. Rupture or incipient cracks resulting from this would not be corrected by any heat treatment alone.

We are therefore confronted with the contradictory state

of affairs that the larger the section the more vigorous should be the cooling; and the more vigorous the cooling the greater the liability to excessive strains or rupture. While the component particles of the material may be advantageously affected, the object as a whole suffers. From this it is evident that for any given size or section there is a maximum relation between the ductility and strength, which decreases as the dimensions increase; that if the strength is maintained constant the ductility must decrease, and vice versa, as discussed in connection with Fig. 32.

It must consequently be realized that the possibilities as regards the physical properties of large sections are not so great as in the case of small sections, and this must be taken into consideration in drawing up the physical requirements of specifications. For, stating the case briefly, under similar circumstances:

First: The condition of the carbon and the grain size depend upon the temperature and the rate of cooling.

Second: The rate of cooling depends upon the diameter or thickness of a given section, and probably also to a certain extent upon the length, or, in other words, upon the mass.

Third: The rate of cooling through the critical range, and just below the lower critical point, is of much greater importance than during any subsequent tempering (after quenching).

To determine the uniformity of heating, the temperature must be of unquestioned accuracy. Further, the rate of heating must be carefully determined by experiment to secure proper penetration. It will be seen that the principles involved are comparatively simple. The main difficulty in carrying out the operations commercially is found in securing the necessary degree of uniformity. It is for this reason that special equipment is so essential. Of equal importance is the proper material, the composition of which must be definitely known, as variations, particularly in carbon, will result in different physical properties being secured under the same conditions of treatment.

MR. T. D. LYNCH: Mr. Grayson discussed the question of manganese in steel and its relation to heat treatment. Let me

say in reply that we find when manganese runs around 0.80 to 0.90 percent we have a great deal of trouble to machine, therefore, we must, on account of machining, keep the manganese below 0.80 percent. We do not have any serious trouble with heat treatment of steel having manganese around 0.50 to 0.60 percent.

Mr. Handy introduced the question of defective heat treatment of locomotive axles. I would like to say that I am convinced that heat treated axle troubles are not all due to heat treatment, no doubt some of it is, but a great many of these troubles begin when the steel is made.

In closing, I would like to emphasize the last paragraph of Mr. Phillips' paper in which he speaks of the importance of cooperation, the working together, of all interested parties, to a common end.

Troubles with gearing cannot always be traced to the heat treatment. The steel maker may have furnished the steel from an off heat, the forging company may heat too hot or not hot enough, forge too lightly or too heavy; or in service the operator may lubricate improperly, permit sand to get into the gearing or perhaps not keep the bearings in proper alignment; any one of which may cause failure.

This thought is brought out to show that the cooperation, in the fullest measure, of all concerned, is most necessary. May I repeat his last paragraph: "Cooperation in the fullest measure between the steel maker, the forging company, the gear manufacturer and the railway operator is the prime essential for satisfactory development."

Mr. Elmer K. Hiles: I wish to express the appreciation of everyone present as well as to extend the thanks of the Society to Mr. Lynch for presenting Mr. Phillips' paper this evening. Mr. Phillips was taken ill very suddenly and Mr. Lynch has had but the briefest time for preparation.

STEAM TURBINE MILL DRIVE

By J. D. Berg.*

The Carpenter Steel Company, of Reading, Pa., have recently installed a low pressure steam turbine for driving two stands of 18 inch three-high mills. About four years ago James Dunlop & Company installed at their Calderbank Steel Works, near Glasgow, Scotland, a low pressure steam turbine for driving a three-high 28 inch plate mill. I believe these two installations are the only ones of their kind.

Briefly, the Calderbank installation consists of a 750 h. p. mixed pressure Parsons turbine, operating at a speed of 2000 r. p. m. This speed is reduced first to 375 r. p. m. and then to 70 r. p. m., the speed of the mill shaft, by means of double helical gears. Both sets of gears are of the solid frame type. This installation is fully described in the Journal of the West of Scotland Iron and Steel Institute Nos. 5 and 6. Volume XVIII.

The Carpenter Steel Company formerly drove their three-high roughing mills by means of a 36 x 36 in. simple engine at speeds of from 70 to 100 r. p. m. according to the nature of the work going through the mill. This engine operated condensing but on account of its type the economy was very poor.

They have a 10 in. and an 8 in. finishing mill belted to a 22 x 40 x 48 in. cross compound engine. This engine also ran condensing exhausting into a jet condenser, the vacuum on which varied from 18 in. to 24 in. Reasonably good economy could have been obtained on the compound engine if the vacuum had been higher, but as the condenser was of an obsolete type, the general operation of this portion of the plant was uneconomical.

The boiler feed water for the entire plant is heated by the exhaust from direct acting service and boiler feed pumps and

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*Vice President, Dravo-Doyle Company, Pittsburgh.

several air compressors, and its temperature is about 210 deg. Fahr. However, there is more steam available for heating feed water than is necessary and the heater is not in the best physical condition.

A little over a year ago a very careful study was made to better the economy of operation, and a number of methods of accomplishing this were suggested.

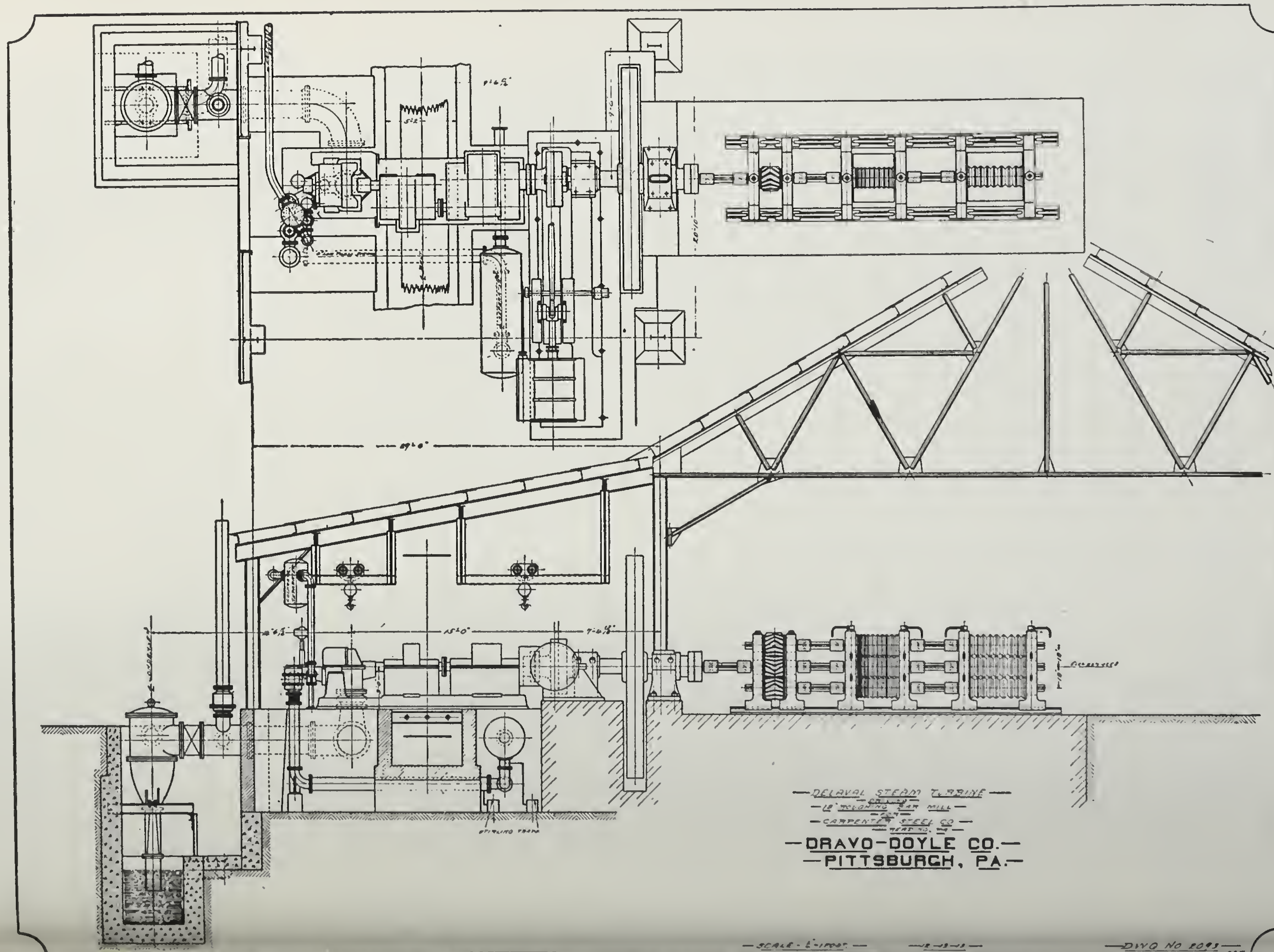
The installation of a new compound engine for driving the roughing mill, and a modern central condensing system were first considered. However, due to the wide fluctuations of load on the engine and the fact that the normal horse power required is comparatively small, the first cost and economy of this type of installation were not attractive.

The installation of a low pressure turbine generator with condenser and motor drive for the mill then was considered. This would have worked out better had there been a bigger demand for power for other purposes in the plant. However, as the majority of the power that could be generated from the exhaust of the finishing mill engine, if it had been operated non-condensing, would have been used on the roughing mill, several disadvantages to this scheme were found. The original cost of the installation consisting of turbine, generator, switchboard, transmission line, starters, motors, etc., would have been considerably greater than the cost of the installation of a turbine geared direct to the mill. The loss of from 15 to 20 percent of the available energy in the steam through electrical generation and transmission would have been far in excess of the gear loss with the direct turbine drive.

It was therefore finally decided to install a low pressure turbine with a double reduction gear connected to the roughing mill and to obtain the steam supply for the turbines by running the finishing mill engine non-condensing.

The old simple engine was direct connected to the middle roll of the mill. Between the crank disc and the wobbler was mounted a 26 ft. fly wheel having a 14 x 22 in. rim weighing 26 tons. There was a heavy bearing between the crank disc and fly wheel, and another between the fly wheel and wobbler.

In the new installation everything was left the same up to



DELAVAL STEAM TURBINE
18" ROUGHING BAR MILL
CARPENTER STEEL CO
DRAVO-DOYLE CO.
PITTSBURGH, PA.
DWG NO 2093

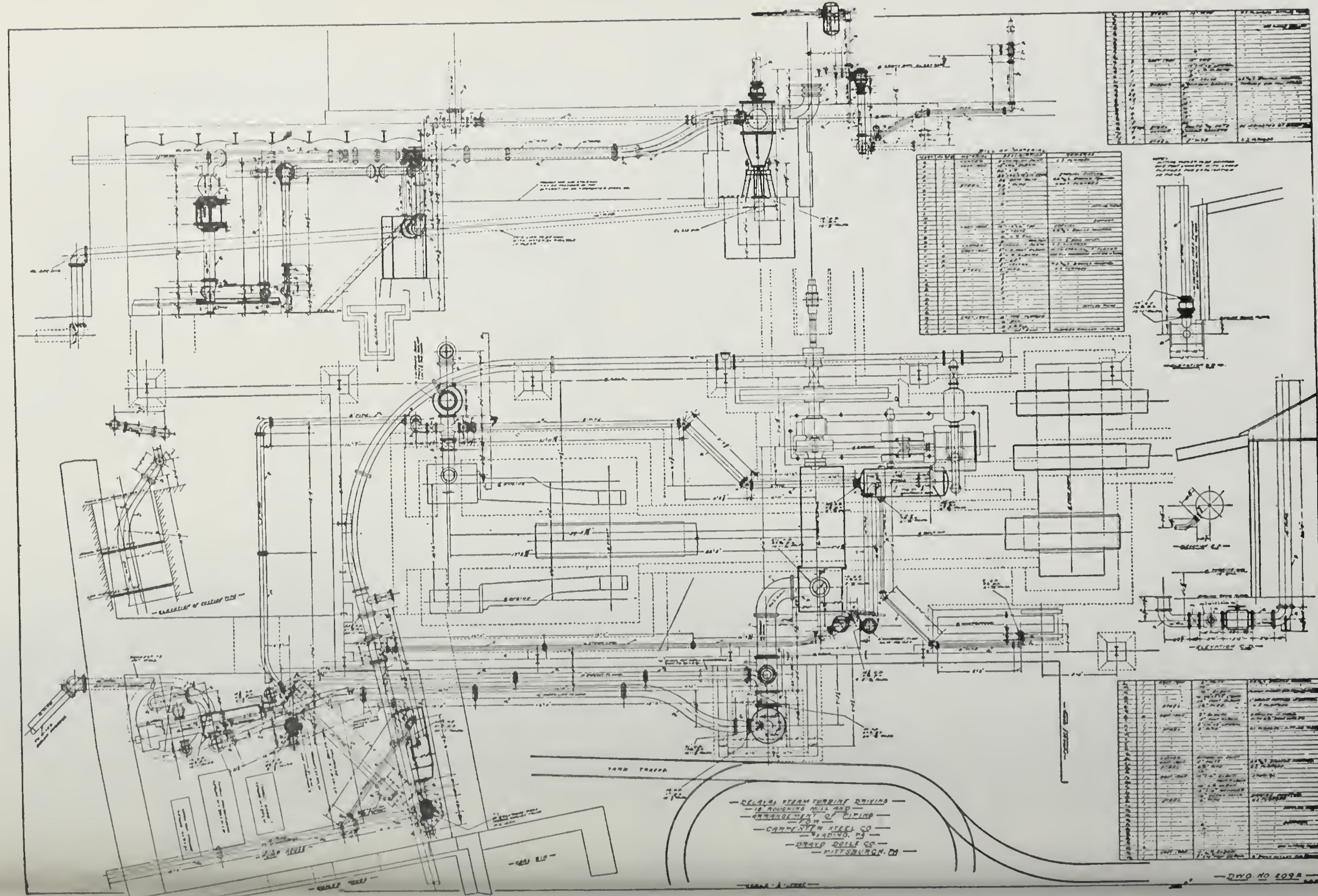
and including the crank disc. The turbine shaft is connected to the first pinion by means of a flexible coupling, and the first gear is connected to the second pinion by means of a flexible coupling. On the second gear shaft is mounted one-half of a flexible coupling. The other half was made up of a cast steel distance piece between the gear half of the coupling and the crank disc.

All the apparatus except the distance piece was installed and operated for several days without load. During this time the old engine continued to drive the mill. After everything operated satisfactorily, the connecting rod of the engine was disconnected and dropped out of the way. The distance piece having a hole cored into it to accommodate the crank pin was then placed and bolted solid to the crank disc.

The idea of this arrangement was to make the change in the shortest possible time and at the same time make it possible to reconnect the engine in case it had been necessary to make any changes on the turbine. The steel distance piece was designed so that it and the crank disc with its counterweight are in rotative balance.

The compound engine driving the finishing mill was taken off the condenser and a new system of exhaust piping installed.

The size of the exhaust from the engine driving the finishing mill is 14 in. A 14 x 16 x 16 x 8 in. cross was connected to this exhaust line. To one 16 in. outlet a multiport back pressure valve was connected to relieve any surplus exhaust steam to atmosphere. From the other 16 in. outlet on the cross a line was run to the condenser which ordinarily serves the turbine driving the roughing mill. An 8 in. branch was taken off this line to supply steam to the turbine. Under ordinary conditions the compound engine runs non-condensing, supplying steam at from 3 to 3½ lb. gage to the turbine. However, when rolling certain sizes of material the roughing mill is not used and the steel is taken directly to the finishing mill. Valves between the engine exhaust and the turbine, and between the turbine exhaust and condenser are then closed and a valve between the engine exhaust and condenser opened, allowing the engine to operate condensing with good economy.



Carpenter Steel Co
Dravo Doyle Co
Pittsburgh

From the other 8 in. connection on the cross a line was run down to the pump room, first for supplying exhaust steam to a low pressure turbine driven circulating pump, and second to make it possible to connect the exhaust steam system in the pump room with the general system. The open feed water heater above mentioned will ultimately be replaced by a larger heater and the connection made to the general exhaust system. This will be done so that in case of a surplus of exhaust steam from the pumps and air compressors over that required for heating the feed water and at the same time a deficiency of exhaust steam from the finishing mill engine, the turbine driving the mill will be supplied with as much exhaust steam as might be available.

The distance from the cross connection above mentioned to the mill turbine is about 55 ft. and the distance from the same point to the pump room about 50 ft.

Very careful attention was given to the question of supplying dry steam to the turbine. In the 8 in. supply line, a special low pressure receiver separator was installed. There is a length of about 12 ft. of straight piping between the separator and the turbine throttle. In this 12 ft. of piping which was made 10 in. inside diameter, a coil of 1-inch copper pipe was placed. A live steam connection was made to this coil at one end and the other end led to a steam trap. This "dryer" arrangement was also used on the supply line to the turbine driving the circulating pump.

Immediately before the low pressure throttle valve of the turbine a Cochrane multiport flow valve is placed. The purpose of this flow valve is to prevent the loss of vacuum in case of failure or partial failure of the exhaust steam supply.

The following velocities were used in deciding on the various pipe sizes:

On the low pressure steam supply to the main turbine 9500 ft. per min.

On the exhaust from the main turbine 26 000 ft. per min. for the maximum condition and 16 700 ft. per min. for the normal condition.

On the water line supplying the condenser 4.6 ft. per. sec.

was used on the discharge line and 3.5 ft. per sec. on the suction line.

The exhaust line from the turbine driving the circulating pump which is about 75 ft. long was figured for future maximum velocity of 25 700 ft. per min. or for the present condition, 15 500 ft. per min. It is proposed some time in the future to install a second pump to be driven by the present turbine. This pump will be used for general supply purposes in the mill.

A study of the power requirements resulted in the turbine being designed for the following conditions:

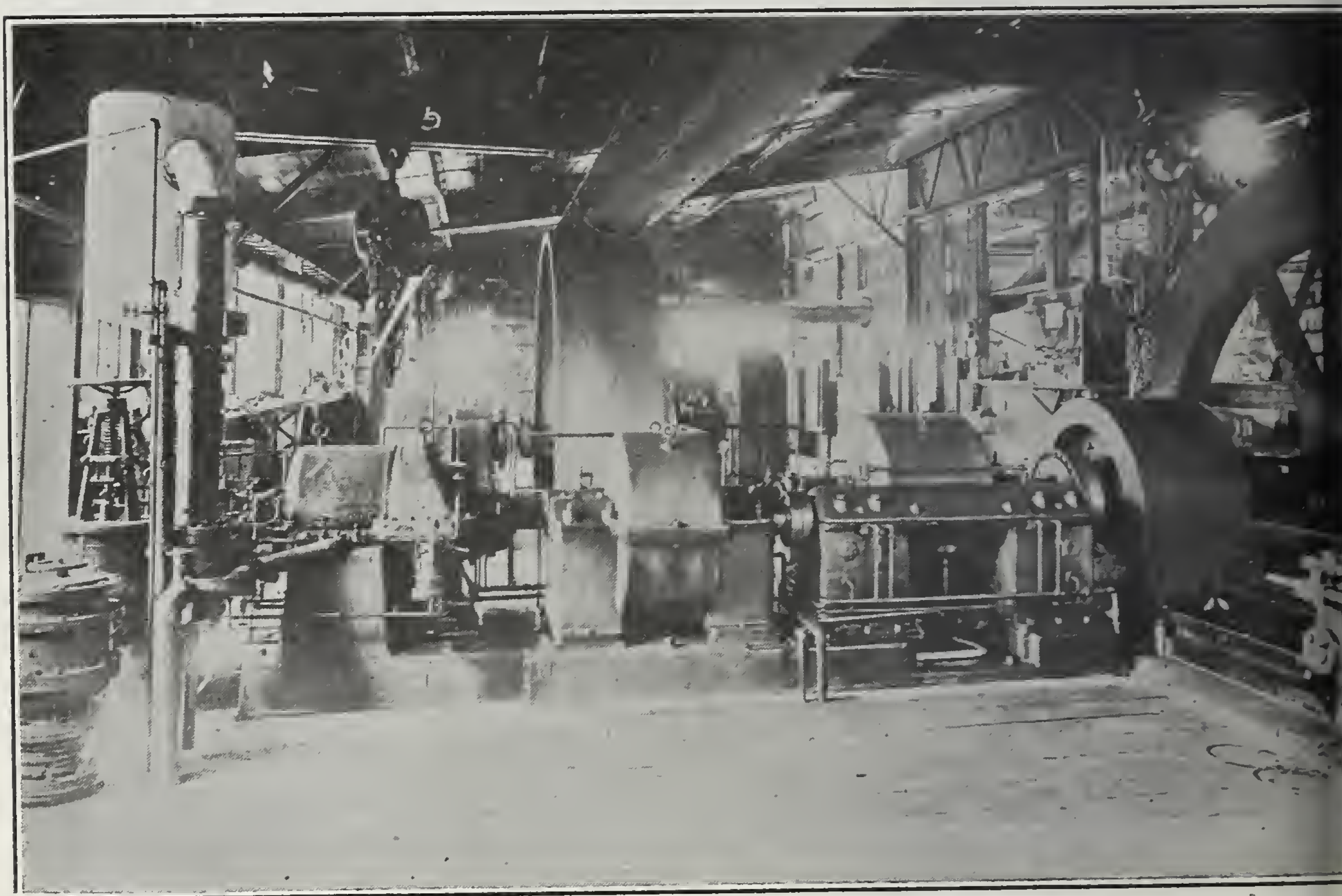


Fig. 3. Turbine and double reduction gear as installed. Part of engine which formerly drove this mill can be seen. This engine is still in place and by removing the distance piece between crank disc and flexible coupling on last gear reduction, it can be re-connected to mill.

With 3 lb. gauge pressure at the turbine throttle, equivalent to between $3\frac{1}{8}$ and $3\frac{1}{4}$ lb. at the exhaust of the compound engine, and with 3 in. absolute pressure in the turbine wheel case, the turbine was designed to carry 350 h. p. at speeds varying from 70 to 100 r.p.m. on the mill shaft.

Under this condition the turbine was guaranteed to take

not more than 26 lb. of steam per brake horse power per hour, a brake horse power being considered at the end of the second gear reduction.

The turbine is of the combination high and low pressure type and is designed to carry normal full load of 350 h. p with 120 lb. steam pressure at the turbine throttle and 3 in. absolute pressure in the turbine wheel case. **Under this condition it** was guaranteed to take not more than 17.5 lb. of steam per brake horse power per hour.

In order to take care of overloads, the turbine is designed to operate with mixed pressure and with steam at 3 lb. gauge on the low pressure side, and 120 lb. on the high pressure side will carry 600 brake horse power continuously.

It is also designed to carry the full overload of 600 h. p. on high pressure steam only, as this is a desirable feature in case it would be necessary to run the turbine when the compound engine is down. Under this condition it was guaranteed to take not more than 15.7 lb. of steam per b. h. p. per hour.

As there may be conditions when it would be desirable to operate the roughing mill during repairs or inspection of the condenser or the pump, the turbine will carry the mill under ordinary conditions with 120 lb. steam pressure and atmospheric exhaust.

Briefly the turbine will operate as follows:

Low pressure condensing,
Mixed pressure condensing,
High pressure condensing,
High pressure non-condensing.

It was considered more desirable to make the turbine extremely flexible to take care of every conceivable condition of operation than to endeavor to obtain the highest possible economy under any particular condition.

The question of starting a mill of this kind with a turbine is one to which very careful attention has been given. No starting troubles have been experienced on this installation as the turbine will start the mill when cold without any difficulty or outside aid.

The turbine is of the De Laval multi-stage, impulse type

containing nine wheels with one row of buckets on each wheel. The first three wheels are used for high pressure conditions only and the remainder for low pressure or combination conditions.

The turbine shaft operates at a speed of 5000 r. p. m. It is geared to 600 r. p. m. and this shaft in turn is geared to 100 r. p. m. The gears are of the double helical involute type with 45 deg. teeth. The pinion teeth in each case are cut in a chrome nickel steel forging. The gears are made up of cast iron centers on which are shrunk rolled steel bands. The teeth are cut in these bands. Each gear set is mounted in a cast iron casting rigid in construction.

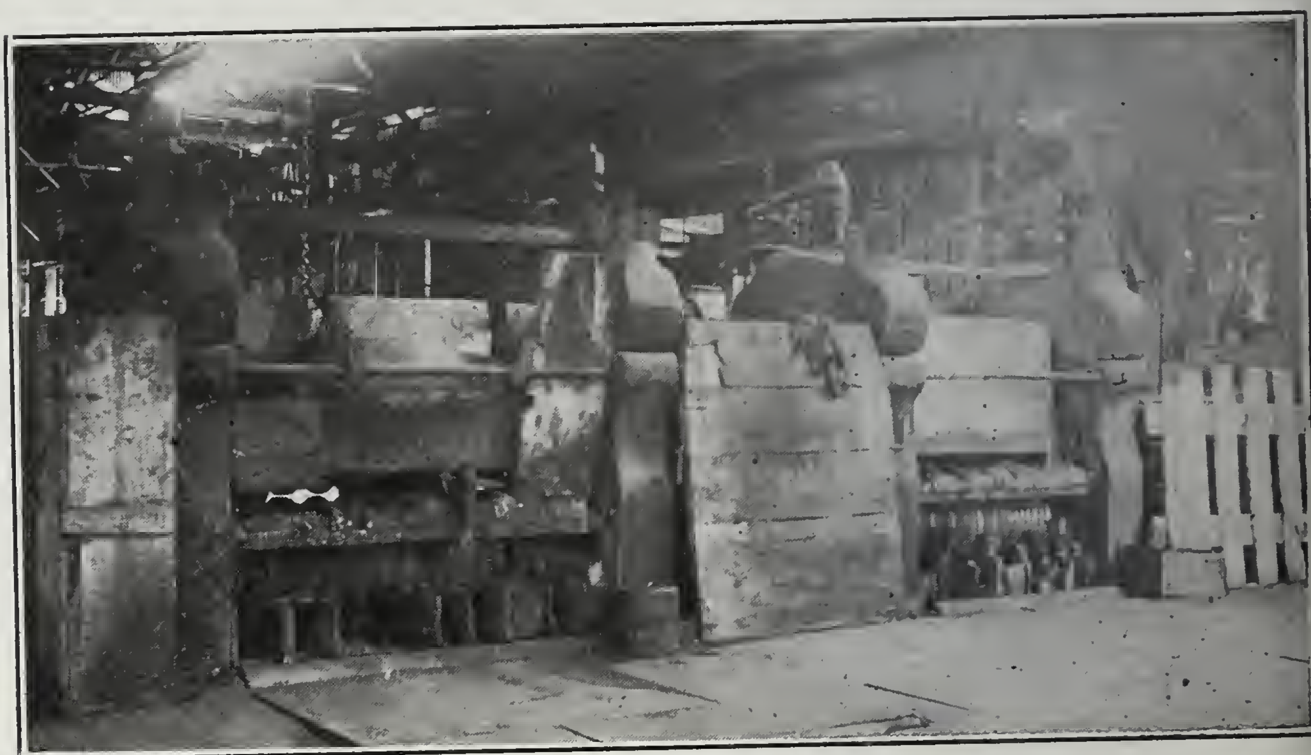


Fig. 4. Mill driven by the turbine.

The pinion and gears were very carefully cut and ground, and are practically noiseless in operation.

The turbine is supplied with a variable speed Jahns governor which can be adjusted while the machine is in operation, giving a speed variation of from 100 to 70 r. p. m. on the mill shaft.

The turbine and gears are supplied with a central oiling system. The governor spindle is extended and drives a geared oil pump, placed in a drain tank at the end of the turbine. The oil is pumped through an oil cooler to a supply tank placed about 15 ft. above the center line of the turbine. This tank

supplies oil to all the high speed bearings, gears and oil relay governor. The slow speed bearings are ring oiled. An oil filter is placed on a by-pass from the oil pump to the supply tank.

A Schutte & Koerting multi-jet type condenser was installed. This type was chosen with the desire to make all the equipment as simple as possible and its economy in this case is better than the economy of those condensers which require air pumps; for the reason that there is a surplus of exhaust steam

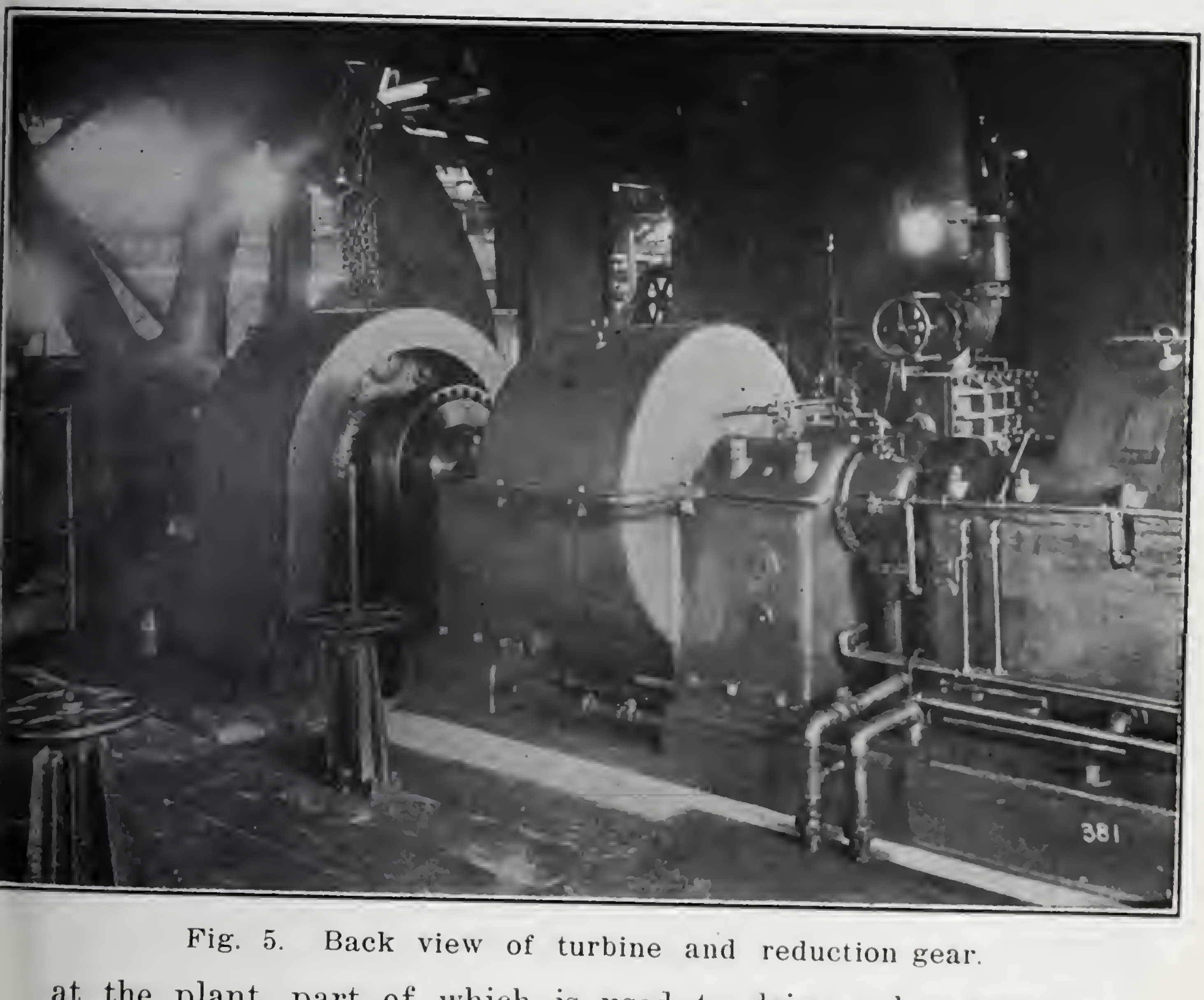


Fig. 5. Back view of turbine and reduction gear.

at the plant, part of which is used to drive a low pressure turbine driven circulating pump, so that no high pressure steam auxiliaries are used.

The piping connection between the turbine exhaust and the condenser was made as short as possible. There is a tee placed in this connection on the top outlet of which is a 10 in. water sealed multiport free exhaust valve.

The water supply pump for the condenser has a normal

capacity of 2200 gallons of water per minute, equivalent to a little over three million gallons per 24 hours against a total head of 50 ft. at 1500 r. p. m. the turbine shaft operates at a speed of 5000 r. p. m. being geared to 1500 r. p.m. required for the pump, the same construction of gears being used as is used on the main turbine.

This pump is so arranged that it can be started and run non-condensing as it exhausts into the same condenser to which it furnishes water. The turbine also will carry full load with high pressure steam operating condensing which is a desirable feature in view of the possibility of there not being sufficient low pressure steam for driving the mill turbine. Preference is given to the turbine driving the mill in the matter of low pressure steam supply.

As stated above the roughing mill driven by the turbine consists of two stands of 18 in. three-high mills. The mills are manually operated, two men being employed on each stand.

The reduction of a 4 in. x 4 in. billet, 17.6 in. long weighing 80 lb. is performed as follows:

Pass	Size	Shape	Reduced Size	Shape	Time of Pass.
1	4 × 4"	Square	3½"	Square	2/5 Sec.
2	3½"	Square	3" × 2⅞"	Rectangular	2/5 "
3	3" × 2⅞"	Rectangular	3"	Square	4/5 "
4	3"	Square	2¾"	Square	1 "
5	2¾"	Square	2½"	Square	1 2/5 "
6	2½"	Square	2¼"	Square	2 1/5 "
7	2¼"	Square	3¼"	Oval	3 "
8	3¼"	Oval	1⅜"	Square	3 "
9	1¾"	Square	2⅛"	Oval	3 1/5 "
10	2⅛"	Oval	⅞"	Square	4 "
11	⅞"	Square	1½"	Oval	5 "
12	1½"	Oval	¾"	Square	7 "
13	¾"	Square	1¼"	Oval	10 "

The above material was high carbon steel, and on account of the fact that the finishing mill engine could not take material faster with this quality of steel, only one billet was in the roughing mill at this time. When rolling low carbon steel there are often two billets in the roughing mill at once.

The 600 r. p. m. shaft is supplied with a tachometer having a 4 inch circle, with speed indications from 200 to 800 r. p. m. in 300 deg. of the circle. During the operation in the

cycle described above, there was absolutely no fluctuation of the tachometer pointer during any of the passes.

However, when two billets are in the mill at the same time during the early passes of the second billet, the speed of the machine drops approximately 2 percent, the high pressure governor valve opens, and there is then a nozzle pressure in the first high pressure stage of from 25 to 50 lb. This opening of

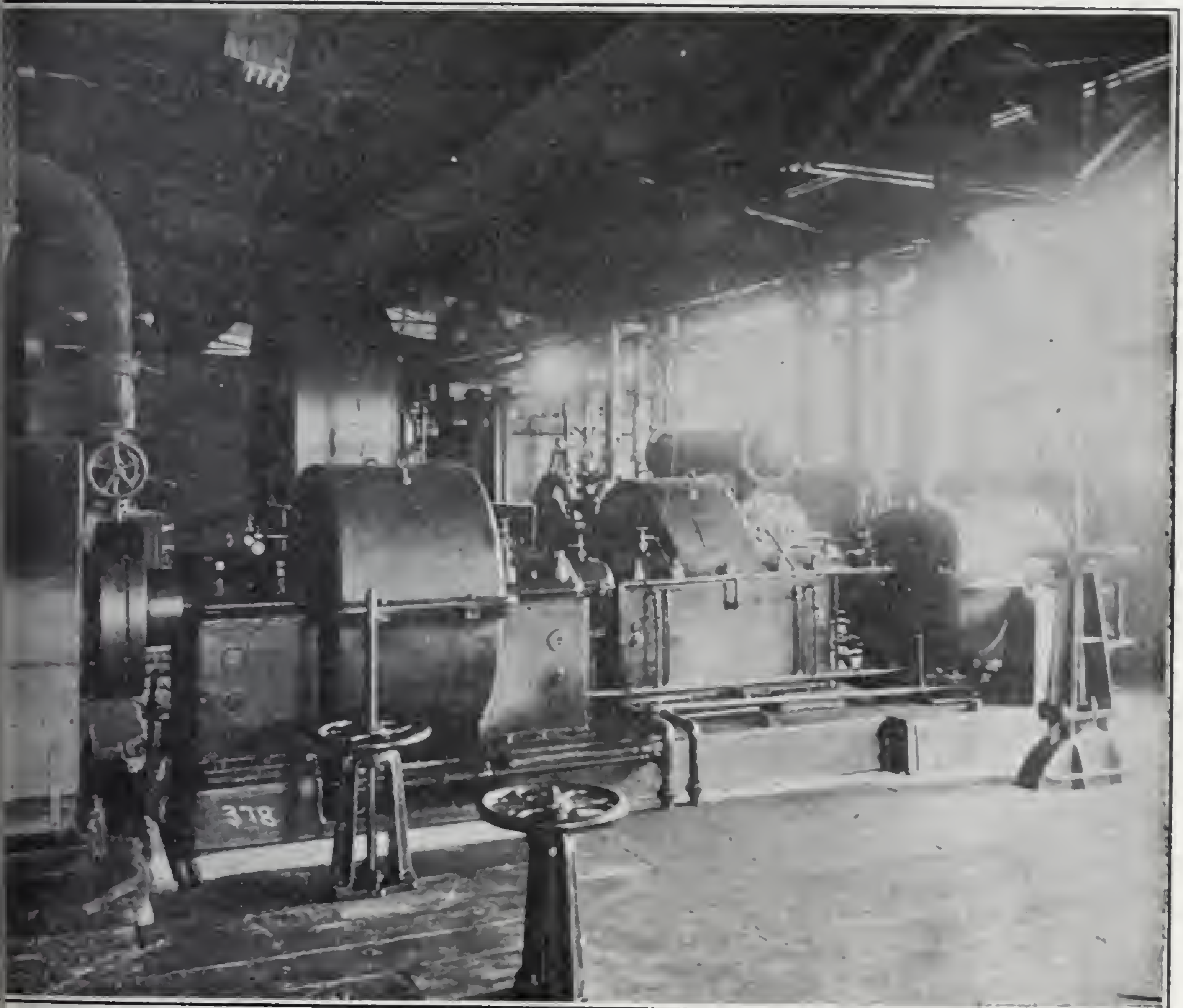


Fig. 6. Second reduction gear and distance piece showing crank pin extending through distance piece.

the high pressure governor valve is momentary and simply indicates that the high pressure governor acts only in an emergency caused by the sudden overload of the second billet.

It will be noted that since during the time when there is only one billet in the mill there is no apparent fluctuation in speed, no advantage is being taken of the 26 ton fly wheel. This

would seem to be poor practice. It must be remembered however that the fly wheel was not installed for the turbine drive, as it was part of the equipment before the change was made. It is desirable to keep the mill operating at as constant a speed as possible, as this results in bigger production. There is an ample supply of exhaust steam available, which goes to atmosphere if it is not being used in the turbine. Therefore

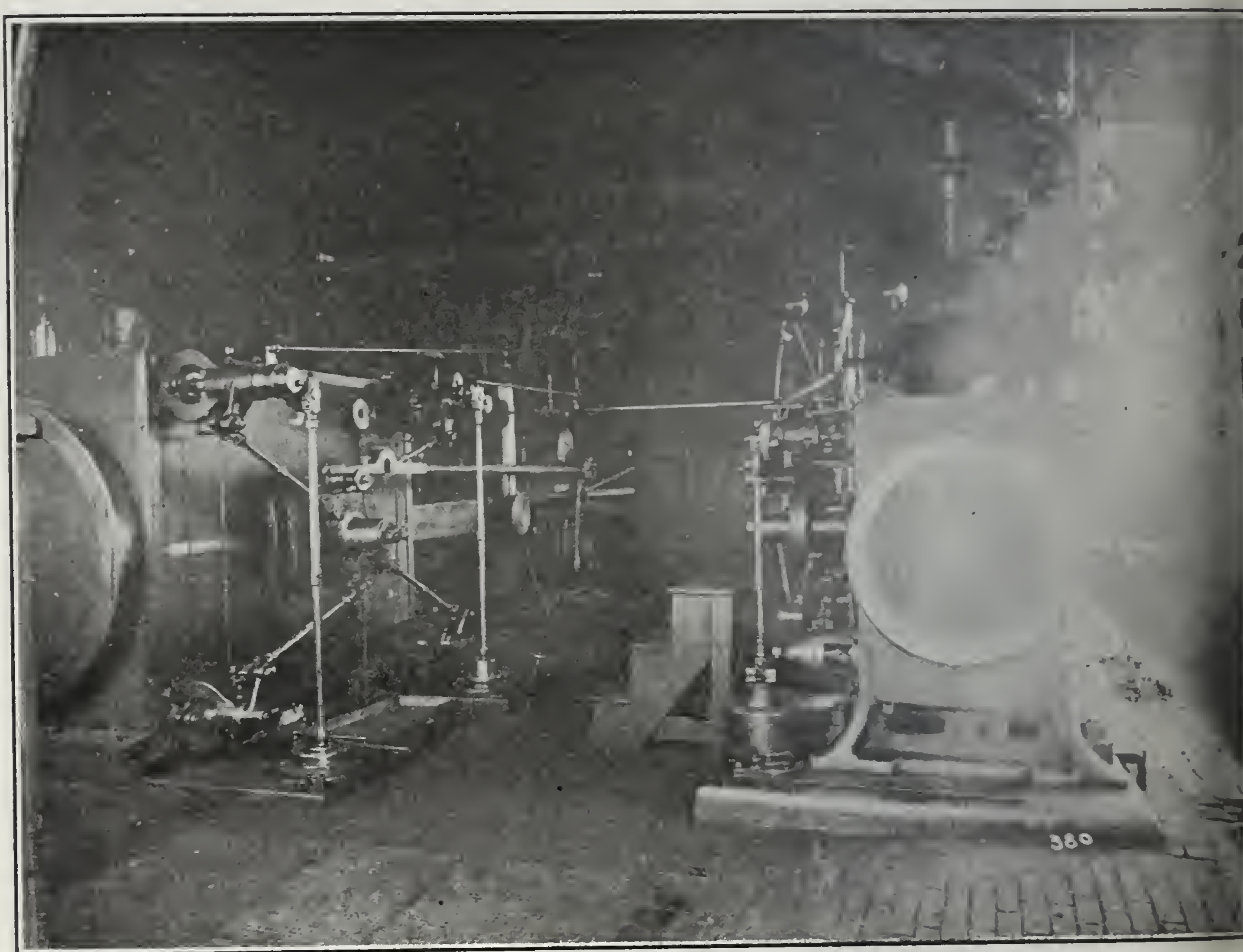


Fig. 7. Cross compound engine driving finishing mill from which supply of low pressure steam for turbine is obtained.

the low pressure governor is made to operate very quickly and on any slight change in speed to open, in order to admit more low pressure steam. However, since high pressure steam has a certain value, when the limit to the capacity of the turbine on low pressure steam only is reached, the fly wheel is utilized up to a speed drop of 2 percent when the high pressure valve opens momentarily and maintains the speed at that point. When the overload disappears the high pressure valve again closes and

the machine runs up to its normal speed on low pressure steam only.

With water at a temperature of 72 deg. Fahr. and the mill operating under normal conditions, a vacuum of 28.2 in. with a barometer of 29.78 in. was obtained. This is equivalent to 1.58 in. absolute vacuum, the vacuum being taken by a mercury column. The tail water from the Schutte condenser with injection water at 72 deg. Fahr. was 81 deg. Fahr.

During the second day's operation it was necessary to take the condenser off to clean a screen in the water system and the turbine was tested for non-condensing conditions at that time. It carried the load very satisfactorily with 120 lb. at the turbine throttle and atmospheric exhaust.

The entire cost of the installation consisting of the turbine, reduction gears, condenser, piping, circulating pump, etc., delivered and erected, approximated \$25 000.

On account of the better economy of the turbine it has been possible to operate the plant on about 300 boiler horse power less than was formerly the case, and to effect a saving of approximately \$15 000 per year in operation.

DISCUSSION

Mr. Frank E. Leahy*: Mr. Berg's description of the first steam turbine to drive a mill in this country is very interesting. As this and the one abroad briefly referred in his paper constitute the only units now operating in this service the results obtained from their use is of large interest to steel mill engineers seeking better economy in mill power.

It is generally recognized that the turbine is a flexible form of prime mover as it may be operated on live, exhaust steam or both. This characteristic is of great advantage in securing better overall efficiency from existing power equipment. For instance, in some mills a number of simple engines still in very good physical condition may have their life prolonged even if they are uneconomical in the use of steam. By passing the exhaust steam from these engines through a low pressure turbine, power may be obtained from steam formerly lost to the atmosphere. If sufficient steam is not available from this source

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a mixed pressure type of turbine may be used consuming live steam to make up for the deficiency in exhaust steam.

At the present time, however, the one point of uncertainty is the ability of the high speed transmission gear to successfully perform its duty under the rather severe service which all mill drives must withstand. The use of the high speed transmission gear cannot be avoided owing to the comparatively low speed of the mill as compared to that of the turbine, so that to insure the adoption of this method of mill drive the reliability of the gear must first be proved.

Regulation is very well secured when the speed is maintained within 2 percent on the mill. As a demonstration of close regulation this is very good, but with any form of prime mover it can only be obtained by means of a large overload capacity, and reserve power supply. The reason given for this close regulation, that "it is desirable to keep the mill operating at as constant a speed as possible, as this results in bigger production," may be true from one point of view.

The same results could be obtained by raising the normal speed of the mill and allowing such a variation in speed as necessary to enable the fly wheel to supply the momentary energy requirements. This would result in a more even demand for steam and a better all-around power condition. The required production per unit of time would be obtained by the increase in speed. A prime mover of a smaller size and less overload capacity could then be used, which would mean better economy during regular operation.

The field for the turbine drive is the one now occupied by the motor and the numerous advantages claimed for the motor drive as to the economy of running, improved drive, space, etc., may be claimed equally as well for the turbine. It is evident that if the electric power is generated by means of steam driven units the motor drive cannot compete with the turbine drive owing to the added cost of generating equipment and its incidental losses in conversion and transmission.

In a Blast Furnace and Steel Works plant where full advantage is taken of the blast furnace gas the problem of the selection of the proper prime mover is usually involved, depending on the location, present equipment, power development

policy of the plant and the class of service it is to perform, so that everything will be in harmony to give the best economy.

In making a comparison between different types of drives we must work to the coal pile and charge to the mill prime mover the cost of all equipment or part thereof that is necessary for its operation. For the purpose of a general comparison between a turbine drive and a motor drive consider the case of the power equipment for a new plant to be designed: First, steam boilers and steam equipment; second, gas engine, electric generators and motor drive. Such part of the cost of the boilers and equipment, or gas engine generators, that are necessary for the operation of the mill prime movers to be charged to the turbine or motor drive.

The mill to have the following dimensions: Rated horse power of prime mover 2000, average horse power 1100, speed of mill 60 r. p. m., product to be finished in 15 passes and mill to be in operation 5500 hours per year.

COST OF INSTALLATION

	Motor Drive	Turbine Drive
2000 h. p. motor installation erected complete with controller, etc.	$ 37,000	
Gear Transmission	15,000	
Gas engine generating equipment erected complete 820.6 k.w. capacity to be charged to motor drive at $80.0 per k.w.	65,648	
Turbine with double gear transmission, condenser, pumps erected complete		$57,000
Blast furnace gas fired boiler equipment erected complete with pumping equipment and pipe lines at $30 per b.h.p.		18,000
Total cost of installations	$117,648	$75,000

YEARLY COST OF OPERATION

	Motor Drive	Turbine Drive
	$1100 \text{ h.p.} \times 746 \times 5500 = 4\,513\,300$ k.w. Hours Allowing 5% line loss $\frac{4\,513\,300 \times 100}{95} = 4\,750\,842$	$\frac{1100 \text{ h.p.} \times 13 \times 5500}{730 \times 30} =$ $= 3591$ b.h.p. months. Allowing 15% condensation. $\frac{3591 \times 100}{85} = 4225$ b.h.p. months
Electric power = 4 750 842 × $0.0036 per k.w.	$17 103	
Steam for turbine 4225 × $2.15 per b.h.p. month		$ 9 084
Steam for circulating pumps 375 × $2.15 per b.h.p. month		806
Repairs	500	1 010
Oil waste, etc.	100	220
Attendance 6240 hrs. at 30c	1 872	1 872
Total	$19 575	$12 992
Fixed Charges		
Depreciation	$ 5 875	$ 3 746
Interest	5 882	3 750
Taxes	1 176	750
Insurance	353	225
Total yearly cost of Operation	$32 861	$21 463

EXPLANATION OF FIXED CHARGES

Depreciation is understood as the amount of money set aside yearly, which compounded at an accepted rate of interest would equal the original investment at such a time as replacement is necessitated through obsolescence, age or inadequacy. The lifetime of each installation was taken at 15 years and the rate of interest was 4 percent compounded.

Interest on the investment was figured at 5 percent.

The amount of taxes chargeable was figured at 1 percent.

The probable insurance premium that would have to be paid on the installation was figured at 0.3 of 1 percent.

From the comparison between the motor and turbine drive, it shows that a motor drive would mean an investment of \$117 648 with a yearly operating cost with fixed charges included of \$32 861; and the turbine drive would mean an investment of \$75 000 with a yearly operating cost with fixed charges included of \$21 463.

The above figures show a difference of \$42 648 in the first cost of installation and \$11 398 per year in the yearly cost of operation in favor of the turbine.

MR. J. S. ALBERT*: I have never had any experience with mill drives, but I know something about engines. I do not quite understand why the effective fly wheel is never used. I would think when the load first came on it would certainly help to carry the load and make a more steady operating arrangement than if the fly wheel is not used.

THE AUTHOR: It is possible there is some advantage gained from the fly wheel, but the fact that the tachometer on the 600 r.p.m. shaft shows no speed fluctuation would indicate that it is not very great. Under ordinary circumstances that would be considered poor practice. It must be remembered, however, that there is a surplus of exhaust steam which goes to the atmosphere in case it is not being used, and the purpose of making the governor quick acting, instead of sluggish, is to take advantage of the available energy rather than let it go to atmosphere.

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Where a money value can be placed on the exhaust steam, the effect of the fly wheel would be taken advantage of down to a speed reduction of say 10 percent.

The question of the higher first cost of the installation to take care of this condition was I believe mentioned by Mr. Leahy. It costs practically no more to make the turbine capable of carrying the overload without help from the fly wheel, as all the parts must be made heavy enough to carry the overload, which means that the only additional cost to take care of maximum conditions without the help of the fly wheel is the small expense of the additional nozzle capacity.

MR. J. S. ALBERT: Is the tachometer reliable enough to measure these small variations?

THE AUTHOR: From 200 to 800 r.p.m are indicated in 300 degrees of a 4 inch circle. Very close readings can be obtained.

MR. J. S. ALBERT: Isn't it necessary to change the speed to make the governor work?

THE AUTHOR: Yes, but that is only momentary. It is probable that some slight advantage is obtained from the fly wheel when rolling only one billet, and of course when the second billet is put in the roll, much greater advantage is obtained.

MR. JOS. BRESLOVE:* What is the largest turbine driven reduction gear with fixed bearings installed to date, and how long has it been in service?

Has the operation of the reduction gear at the Calderbank Steel Works, Scotland, been successful?

As a matter of interest, the first application of a high speed reduction gear to direct mill drive was carried out at the Calderbank Steel Works, Scotland. A 750 k.w. Parsons type mixed pressure steam turbine operating at 2000 r.p.m. is direct coupled to a three high mill with rolls 28 in. diameter by 84 in. long, through two gear sets, bringing the mill shaft speed down to 70 r.p.m. The first gear set has a reduction from 2000 to 350 r.p.m., and the second set from 375 r.p.m. to the mill shaft speed of 70 r.p.m. Flexible couplings are fitted between the turbine

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and the high speed pinion shaft, and also between the first and second reduction gears. The low speed gear is keyed directly onto the end of flywheel shaft which carries a 23 ft., 100 ton flywheel and is supported between two heavy bearings. The main pinion of the mill is connected to the flywheel shaft, through the usual type of wobbling coupling. Both gear sets are arranged in castiron gear cases. They are of the double helical type with the teeth at an angle of 23 deg. with the axis of the shaft.

This installation was placed in service Sept., 1910. The mill is used in reducing slabs 4 in. thick to sheets about $\frac{3}{16}$ in. in thickness. Tests made in the mill show that during the heaviest passes power was being used up at the rate of 2500 h.p.

The installation described by the author provides for all adjustable back pressure valve in the engine exhaust line. The function of this valve is to always keep the pressure in the exhaust line above atmosphere. The inlet pressure on the low pressure turbine varies with the load, and at times of light load the pressure in the engine exhaust line would be lower than atmosphere, causing an infiltration of air through the engine stuffing boxes and exhaust lines if they are not tight, thus impairing the condenser vacuum. Furthermore, since the pressure in the engine exhaust line would be alternately under vacuum and under pressure during light and heavy loads respectively, it is often difficult to keep the average exhaust line tight. However, with the back pressure valve installed ahead of the turbine throttle the engine will be operating at practically constant back pressure up to a certain load, so that during light loads there is a certain loss due to this method of operation. Where the load is to be divided between the engine and turbine and the engine exhaust line has been properly installed, the turbine governor should be set so that the turbine inlet pressure will be approximately the same as that of the engine exhaust. The most economical operation will take place under these conditions.

The Author: The largest turbine driven reduction gear with fixed bearings I know of, that has been installed to date, is a 4000 k.w. direct current turbine generator. I do not know how long this has been in service, as I have not had a very ac-

curate description of it. However, I know of a 1500 k.w. direct current geared generator that has been in operation for about two years and a half.

I inspected the Calderbank installation about two years ago and an examination of the gears and pinion showed they were in excellent condition with apparently no wear.

MR. W. P. CHANDLER:* I would like to ask Mr. Berg about how long the relief valve is open in the low pressure steam line to the turbine. You say the supply of low pressure steam is practically unlimited, so that you do not have to make use of the fly wheel to take up ordinary peak loads. This means that you must be wasting low pressure steam through your relief valve a great deal of the time.

THE AUTHOR: Up to 350 or 375 h.p. there is more exhaust steam available than we are using. The relief valve to the atmosphere is ordinarily open except when there is a sudden overload caused by entering the second billet.

MR. H. C. CRONEMEYER:† Is the operation of the mill continuous? I should think that there would be a shortage of low pressure steam after a pause in the rolling operation, when steel is in the turbine driven roughing rolls, but when the engine driving the finishing rolls is running idle. Does the turbine work at high pressure steam at such times?

THE AUTHOR: The operation of the mill is continuous and there is a shortage of exhaust steam when starting and before the first piece has reached the finishing mill. That is the purpose of connecting this system to the general exhaust steam system. As stated, there are a number of very uneconomical auxiliaries in the pump house, with part of their exhaust going to the atmosphere the greater part of the time. The feed water is heated to a temperature of 210 deg. Fahr.

The purpose of carrying a full size line from the compound engine down to the circulating pump was to make available for use in the turbine driving the mill as much exhaust steam as possible. This connection has not yet been made, and it is now necessary to use high pressure steam when starting.

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†Efficiency Engineer, Jones & Laughlin Steel Co., Aliquippa, Pa.

Mr. H. C. Cronemeyer: The finishing mill is piped to run either condensing or noncondensing. Have arrangements been made to alter the exhaust valve setting for such changes of operating conditions?

The Author: The valve setting on the compound engine would have to be changed in case the finishing mill engine were run condensing. Since the installation was made it has not been necessary to run the finishing mill engine condensing.

Mr. Snyder: Does the cross compound engine use any more steam now than it did before? I was talking with the manager down there and he said to me "The installation of this turbine is a great improvement. I find we have more area under our curve on the cross compound engine than we did before." I just want to ask how he got his larger area.

The Author: The finishing mill engine uses more steam than it did formerly, as it is now running non-condensing, whereas before it ran condensing. The big saving in steam comes from the fact that the steam is expanded down to 28 or 28¼ in. vacuum instead of to 18 in. as was formerly the case. The saving is indicated by the fact that they operate now on 300 b.h.p. less than was formerly the case.

Mr. Lloyd Jones*: If I understood the speaker he stated that when rolling one bar of soft steel there was a surplus of low pressure steam, as about ¼ of it was exhausted into the air, and if they rolled two bars of soft steel in the mill, all the low pressure steam was used and occasionally some high pressure steam admitted. When rolling billets of hard steel, they rolled only one billet at a time. Is that correct? Could they roll two billets of hard steel in the mill at the same time, and if so would it be necessary to admit high pressure steam to the turbine continuously?

The Author: Yes, they roll one billet at a time. They could roll two bars of the high carbon steel at the same time if the capacity of the finishing mill were great enough to take care of it. When rolling high carbon steel the finishing mill

*Assistant Chief Engineer, United Engineering & Foundry Co., Farmers Bank Building, Pittsburgh.

engine has to run slower, which of course puts a limit on the amount of steel the roughing mill engine can roll.

Mr. A. G. Ahrens*: I have listened with pleasure to Mr. Berg's paper, and I wish to express my thanks for the opportunity to hear it.

I have just been reviewing in my mind Mr. Berg's description from an electrical engineer's standpoint, and there are one or two points in my analysis that may be of interest.

This is a small mill. And in the consideration of motor drive, it was necessary to include a generator. Mr. Berg intimates that a generator just large enough to drive the motor and, in turn, the mill, was considered. If the mill were larger, or if there were use for additional electric power for driving cranes, mill tables, shears, machine tools, etc., a larger generator could be installed to advantage. And the over-all economy of the installation and first cost would have been more favorable to the motor drive.

It seems to me that Central Station power might have induced favorable consideration for motor drive. This sort of load is becoming recognized as very desirable by most Central Station Companies, and they are using every effort in soliciting same. It may be of interest to know that the Painter Mills, on the South Side, are now operating four 500 h.p. motors on central station power, and will soon put into operation two 500 h.p. and two 800 h.p. additional motors. Does Mr. Berg know whether central station power was considered?

A big advantage of motor drive is the elimination of isolated steam generating stations, which are necessary in large plants to avoid an expensive and wasteful steam distributing system. In this case, I understand this is the only mill in the plant, or at least the only mill whose drive was taken into consideration.

With motor drive, very effective use of the fly wheel now installed could be made. I understand from Mr. Berg that there are some reasons why best use is not made of the fly wheel effect available in the drive, and which was part of the old reciprocating engine equipment.

*Engineer, Industrial and Power Department, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

I would like to ask Mr. Berg if he can give us approximately the percentage efficiency from the mill shaft back over the turbine. Also, when was the equipment put into operation?

THE AUTHOR: The installation was put in operation some time in June. I do not know whether Central Station power was considered, but with the conditions existing doubt that it would have been possible to show the desirability of buying power. I do not understand exactly what you mean by efficiency from the mill shaft back to the turbine. I can give you the thermal efficiency if that is what you refer to.

MR. A. G. AHRENS: No, in regard to the percentage of power used.

THE AUTHOR: It would seem the only answer to your question would be to give the thermal efficiency of the turbine including the gears. This would be approximately 56 percent when running under low pressure conditions.

In this case we of course were able to show considerably greater saving by the installation of the turbine geared direct to the mill than with the installation of a low pressure turbine generator.

In other cases, however, where a commercial value can be placed on the excess exhaust steam, and where additional power can be used in the mill, the saving would not be so great. Each particular installation has to be figured on its merits and it is practically impossible to make a general statement which will fit all conditions.

MR. GEORGE H. DANFORTH: What is the material rolled on this mill used for chiefly?

THE AUTHOR: The material rolled by this mill is used for safety razor blades, automobile parts, projectiles, etc.

MR. FRANK E. LEAHY: The remark made in Mr. Berg's paper that "there is an ample supply of exhaust steam which goes to the atmosphere if it is not used in the turbine" suggests to me that a possible means of securing better economy would be to consider "bleeding the receiver" for steam to supply the

turbine and run the finishing mill engine condensing. As every pound of steam exhausted to the atmosphere is equivalent to so much coal lost, every means should be taken to avoid this loss, especially in a district where coal is so expensive.

THE AUTHOR: The suggestion of taking the supply of steam from the receiver of the compound engine running the engine condensing and the turbine also condensing might be worked out. However, this would complicate the installation somewhat and we hardly believe on this size it would work advantageously.

MR. J. A. HUNTER:* Would it not have been possible to have carried the vacuum back through the turbine so as to get some benefit in the engine, and operate at an initial pressure below atmosphere in the turbine and thereby increase the economy of the combined unit?

THE AUTHOR: The only trouble I would see to Mr. Hunter's suggestion would be in the matter of governing the turbine. The design of the governor to operate under variable loads with variable vacuum might offer some difficulty.

A MEMBER: That condition has been worked out and is being used in practice in several cases. But the great trouble is not governor regulation but that the exhaust lines from the engines are partly under vacuum at times and partly under pressure at other times. The governor proposition has been worked out nicely, but the difficulties are more in practical operation. The situation is not at all impossible if the turbine is right next door to the engine, so to speak.

THE AUTHOR: The turbine in this case is approximately 50 ft. from the engine.

It would have been very interesting if Mr. Leahy had included in his comparison the figures for a compound engine besides those for electric motor and turbine drive.

MR. FRANK E. LEAHY: I have no figures to present for such a comparison, but I think a compound condensing engine

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in this case would not show to advantage because of the increased maintenance charges, as compared to a turbine, and its inability to give good steam economy on fluctuating loads.

The Author: That was the main trouble on this particular installation. With a normal load of 250 or 300 h.p. and a maximum load of only 350 h.p. for low pressure steam and 600 h.p. for high pressure steam, the economy of a compound engine did not compare very unfavorably with the turbine.

Mr. A. G. Ahrens: I do not remember what figures the previous speaker used for depreciation on motor drive, but it may be of interest to know that the Westinghouse Company have installed some motor drives on main rolls, on which the maintenance costs are astonishingly low. I have in mind two 1500 h.p. motors installed on re-rolling mill at Edgar Thomson Works. The motors have been installed over eight years, and the only maintenance has been renewal of brushes. I have this information from a reliable source. In eight years the maintenance charges have only amounted to a few dollars. This is an exceptional case, of course, but I find that a great many people have the impression that a motor is a delicate piece of apparatus. It should be noted also that a motor has advantages that are not apparent in a discussion of maintenance figures. But this is not the time to go into them.

Referring to the first part of the discussion this evening, I would like to point out in regard to the use of the fly wheel effect in a drive, that motor drive is very advantageous. Did I understand Mr. Berg to say the mill has two roll speeds?

The Author: The turbine will operate at any speed between 70 and 100 r.p.m.

Mr. Frank E. Leahy: The figures used in the cost of motor drive were taken with some slight modifications from a paper read before the Association of Iron and Steel Electrical Engineers by Mr. Brent Wiley, and printed in their 1913 Proceedings. The figures on maintenance quoted by Mr. Wiley appear conservative.

The Author: I think that is a very good point. I might refer to a letter I received several days ago from a man who operated a De Laval turbine driving a generator for seven years. He stated that he had not spent five cents for repairs in that time. That of course is an exceptional condition and I believe Mr. Leahy's figures are more representative of actual practice than the figures the former speaker gave or the figures given in the letter just quoted.

TEST OF LARGE REVERSING ENGINE AND ROLLING MILL

By Karl Nibecker*

[This paper with numerous discussions was published in the July, 1914, issue of the Proceedings of the Society. Additional discussion, if received, will be published in a succeeding issue.]

Mr. Charles Fitzgerald, Jr.†: In further reply to Messrs. Nibecker and Trinks on the subject of friction load of the blooming mill engine at the Youngstown Sheet & Tube Co. I would like to call attention to a few real facts and figures before the erroneous value of 9.8 percent has received any wider circulation. In reference to the discussion of both gentlemen, it must be admitted that the fact that it has modern features, does not affect materially the results of calculations on the test data of the Youngstown engine. The tendency in this discussion has been to force the acceptance of an absurdly low value in spite of a large number of very definite figures to the contrary.

From an inspection of the tables in Mr. Nibecker's paper the following may be observed:

Test Number	Friction Load
16	9.8%
15	16.4
7	17.8
9	19.0

Test No. 9 was calculated by Prof. Trinks and in spite of the evidence furnished by his own calculation, in addition to that furnished by Tests No. 15 and 7, the professor seems to unduly favor the low value from Test No. 16.

The friction load of any engine is dependent upon two factors: The efficiency of oiling system and the weight of moving parts. If the Youngstown engine be modern in respect to

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†Assistant Experimental Engineer, Duquesne Works, Carnegie Steel Company, Duquesne, Pa.

the former, which will readily be admitted, it is decidedly antiquated in respect to the latter, since the weight of its moving parts is from 35 to 70 tons greater than in similar engines, which have been designated by Messrs. Nibecker and Trinks as "not modern".

All the evidence would, therefore, seem to point to the fact that an error must have been made in arriving at the value of 9.8 percent and such is the case. The friction work for Test No. 16 was considered only for that part of the time during which the cylinder effort was positive, ignoring completely the friction work during the remainder of each reversal period, which is just as much a part of the total loss. All other tests, quoted by Mr. Nibecker as having friction losses of from 14 to 25 percent and Tests No. 15, 7 and 9 were calculated for the total friction, so in order to be comparative, Test No. 16 must also be calculated in this manner, giving a result of 16 percent. The average of the four tests then becomes 17.3 percent, which may be considered a just figure for the engine, or 76.5 percent greater than the value of 9.8 percent. Considering the very heavy moving parts of the engine, the value of 17.3 percent demonstrates the presence of a good oiling system without the necessity of being cut nearly in half by means of a deviation from the form of calculation which had been adopted for the test by all interested, and which had been used on all similar tests from which comparative figures were quoted.

Since the Brier Hill engine was mentioned by Mr. Nibecker, in this connection, it may be noted that in view of the much lighter moving parts and Walchaert valve gear, the friction value of 13 percent for this engine is quite consistent with a value of 17.3 percent for the Youngstown engine.

Mr. Karl Nibecker*: In reply to Mr. Fitzgerald's further discussion of paper upon "Test of Large Reversing Engine and Rolling Mill" with especial reference to value of friction load as reported, I wish to call attention to several facts.

The real measure of the operation of the engine and mill is shown in Table No. 5, page 561 and in Fig. 30, page 590, Vol. 30, No. 6 (1914) of the Proceedings. The thing that vitally

*Authors Closure.

interests the practically operating engine and producing department is the amount of steam required to roll a ton of steel. These quantities are given in the above table and figure. At the bottom of page 590 will also be found some figures as to the amount of steam actually used by this mill over a considerable length of time. It, therefore, does not seem especially pertinent to discuss and question at such great length the matter of friction load.

Due to the methods of calculating the distribution of work, the fact of increasing the percent used by friction will reduce the percentage of power required to roll the steel. As the friction work is small in comparison with the rolling work, the change in friction work is a much larger percentage than the corresponding change in work required to deform the steel. Therefore, the figure of 76.5, as mentioned by Mr. Fitzgerald is in reality only 76.5 percent of 9.8 percent, or 7.5 percent of the total work. This figure of 76.5, as given, is therefore somewhat misleading.

As regards correcting the friction work of Test No. 16 to correspond with the methods used by Mr. Fitzgerald, I would call attention to the fact that the figure of 16 percent, as given by Mr. Fitzgerald is not correct. This figure should be 15.57 percent.

In the tabulation given by Mr. Fitzgerald of various friction loads obtained from the several sets of indicator cards, it is unfortunate that Mr. Fitzgerald has neglected to include the figure of 13.8 percent friction as obtained by Mr. Coryell from the set of indicator cards which he calculated from the Youngstown Sheet and Tube Company engine. If this number of 13.8 percent obtained by Mr. Coryell, which was calculated by the method which Mr. Fitzgerald advocates, is inserted and Test No. 16 is properly corrected to 15.57 percent, the average becomes 16.51 percent and not 17.3 percent, as given by Mr. Fitzgerald. Thus the difference in percentage of friction above 9.8 becomes 68.4 and not 76.5, as mentioned by him. In case this is figured as the percentage which the 9.8 given by us is low, the number becomes 40.6 percent instead of 76.5 percent, which does not look as appallingly large as the latter figure.

The question of the method of calculating the friction work of such an engine further emphasizes the necessity of a suitable commission to standardize such matters.

In defense of the method used in calculating Test No. 16, we beg to offer the following facts. The friction work over the time when the engine is doing negative work, i. e. when the engine is being stopped, is tending to aid the retardation, or is a decided advantage. The ideal thing, therefore, would be to have an engine with as low friction as possible during the time of acceleration and as high a friction as possible during the time of retardation. This, of course, is manifestly mechanically impossible. Therefore, since the friction during the time of retardation is an advantage, we are at a loss to see why this quantity should be included. It will thus be seen that it is necessary for the engine to develop enough excess power to overcome the friction during the acceleration period, but not during the retardation period. Our method, therefore, is to include only the friction during the time of acceleration and to figure this friction only as the percentage of friction.

In methods used by Mr. Fitzgerald, it would seem that in order to be perfectly fair, if the friction during the time of retardation is added as friction work, that this friction should also be added to the negative work, as it would have the effect of increasing the negative work area, although it would not appear on the *M. E. P.* diagram, as it is assisting in retarding the engine.

As regards Mr. Fitzgerald's reference to the Brier Hill Engine having a friction load of 13 percent, being quite consistent with the value of 17.3, which he figured for the Youngstown engine, when the difference in weight of moving parts is considered, we would call attention to the fact that Mr. Coryell, who made the test of the Brier Hill engine, obtained 13.8 as the friction value of the Youngstown Sheet and Tube engine. In order, therefore, to be absolutely certain of making the comparison upon the fairest basis, we suggest the comparison of the percentage of friction of the Brier Hill engine and of the Sheet and Tube engine from the figures as calculated by Mr. Coryell for the two engines. For the Brier Hill engine he

obtained a value of 13 percent and for the Youngstown Sheet and Tube engine, a value of 13.8 percent. As these were both calculated by absolutely the same methods and by the same person, they are certainly comparable in every way, and it would seem as though it is highly probable that the friction work of the Youngstown Sheet and Tube engine might be in the neighborhood of 14 percent, when figured by the very methods which Mr. Fitzgerald advocates, as these are the ones used for this calculation by Mr. Coryell. We, however, beg to defend our calculation in that if the value of 13.8 percent, as submitted by Mr. Coryell is reduced to the methods used for Test No. 16, the percentage of friction would probably be in the neighborhood of 9.5 percent, which certainly checks the value of 9.8, as calculated by us.

MAGNOLIA CUT-OFF IMPROVEMENT ON THE BALTIMORE AND OHIO RAILROAD

By A. W. Thompson.*

INTRODUCTION

When asked by your President and Secretary to come here and tell you something about the Magnolia Cut-Off Improvement now under construction on the Baltimore and Ohio Railroad, it occurred to me that it would probably be interesting to you for me to preface my paper with a brief history of the development of the Baltimore and Ohio Railroad, including an account of the early surveys and construction of the road, the increased business and consequent demands which necessitated this improvement at a time when expenditures on railroads were, generally, being curtailed.

The necessarily limited time in which to present such a great engineering as well as interesting operating problem, prevents a full discussion of details, such as some would care to hear.

If any of the members of this Society, or others desire additional information, our Chief Engineer, Mr. F. L. Stuart, will be glad to delegate a representative to accompany them over the improvement, or will furnish the information by letter.

EARLY HISTORY AND DEVELOPMENT OF THE BALTIMORE AND OHIO RAILROAD

ORIGIN OF THE COMPANY

In looking for the origin of the Baltimore and Ohio—which was one of the first railroads, if not the first, operated in this country—we must go back as far as 1826. About that time attention was aroused to the fact that the development of roads

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and canals in Pennsylvania and New York had diverted from Baltimore a large portion of the trade she had built up in the West. It is a well known fact that long before the steamboat ploughed its wake across Lake Erie or even before a stage route existed between Buffalo and the Mississippi Valley, emigration and traffic had marked a path across the mountains from Philadelphia and Baltimore to Cincinnati and beyond. To Baltimore, especially, this trade became an important factor in the prosperity and wealth of the community; but, when the Alleghenies were turned by the long circuit via the lake route, Baltimore lost a large portion of that commerce which Philadelphia and New York found and enjoyed. In 1826, Philip E. Thomas, a Quaker merchant philanthropist and president of the Mechanics Bank of Baltimore, and George Brown, son of the distinguished merchant Alexander Brown, a director in the same banking institution, took up the subject for careful consideration. The result of their conferences and deliberations was the conviction that unless early and adequate means could be devised to recover this trade it would be ultimately lost to their city forever.

The proposed Chesapeake and Ohio Canal had been generally looked to by the citizens of Baltimore as the readiest avenue to the recovery of their receding vantage ground; but that hope failed them in July, 1826, upon the publication of the estimate of its probable cost and the formidable difficulties which lay in its path because of the scarcity of water and the high elevations over which it must be carried. The citizens became satisfied that the canal would be of no practical advantage to Baltimore for the transportation of passengers and merchandise to and from the West. Philip E. Thomas, earnestly leading in this expression of sentiment, at once resigned the position he then held as a commissioner on the part of Maryland in the Chesapeake and Ohio Canal Company, and from that time he and his associate, George Brown, devoted their entire energies to the formation of the Baltimore and Ohio Railroad Company.

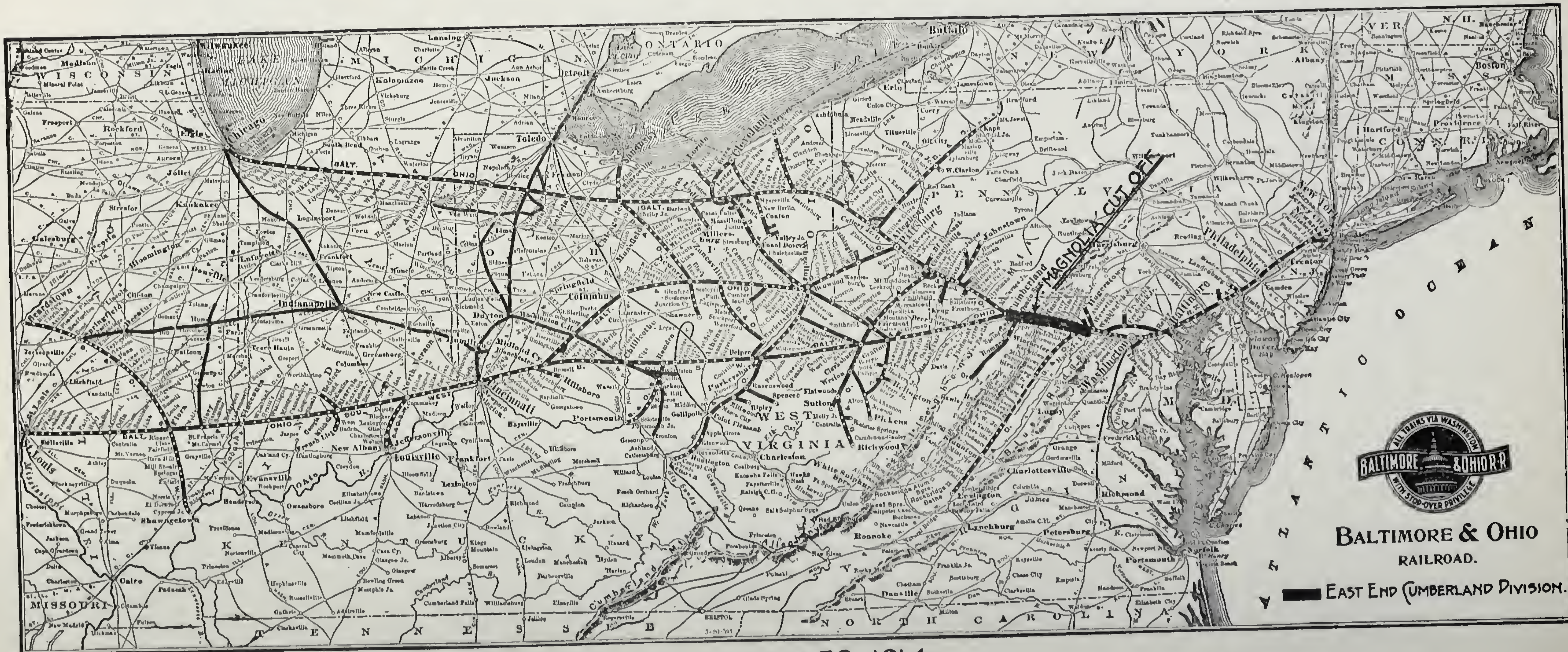
The bold creative enterprise of these men will be more appreciated when it is remembered that previously, no railroad had been constructed either in Europe or America for the con-

veyance of passengers and merchandise between distant points. A few railroads were operated in England for local purposes, such as the transportation of coal, iron and other heavy articles from the mines or places of production to navigable waters; but for the purposes of travel and trade they were still untried, and so meager was public information on the subject that the question had not been settled whether stationary steam engines or horses would be preferable as motive power.

Philip E. Thomas and George Brown, having collected and carefully studied the available information in regard to railroad enterprises in England as obtained from friends residing abroad, became fully convinced that the future commercial prosperity of Baltimore depended on the early completion of a railroad, which they foresaw could be constructed to connect Chesapeake Bay with the western waters. Accordingly, they invited about twenty-five influential merchants and capitalists of Baltimore to meet them on February 12, 1827, to consider the best means of restoring to Baltimore that portion of the western trade which had been diverted from it. Before these men were laid intelligent data on the subject of railroads clearly establishing their superiority over any other mode of conveyance. A committee was appointed to report its opinion thereon and to recommend such a course as might be deemed proper to pursue. The meeting adjourned till the following Monday, when a report was presented by Chairman Thomas for the Committee. It was an able document which, today, in view of the wonderful fulfillment of its confident anticipations, may be looked upon almost in the light of prophecy. In tribute to the far-seeing sagacity and practical wisdom of its author, a few extracts will be given.

After covering the question of Baltimore's declining trade, the report proceeds to say:

"But important as this trade is to Baltimore, it is certainly of minor consideration when compared to the immense commerce which lies within our grasp to the West, provided we have the enterprise to profit by the advantages which our local situation gives us in reference to that trade. Baltimore lies 200 miles nearer to the navigable waters of the West than New York and about 100 miles nearer to them than Philadelphia, to which may be added the important fact, that the easiest and by far the most practicable route through the ridges of the moun-



—June 30, 1914—

Miles of Road Operated ——4 478 Number of Locomotives—2 365

Number of Passenger Cars—1 292 Number of Freight Cars—88 055

Number of Employees—55 000.

Fig. 1. The Baltimore and Ohio System.

tains which divide the Atlantic from the western waters, is along the depression formed by the Potomac in its passage through them. Taking then into estimate the advantages which these important circumstances afford Baltimore in regard to this immense trade, we again repeat that nothing is wanted to secure a great portion of it to our city but a faithful application of the means within our own power.

"The only point from which we have anything to apprehend is New Orleans; with that city, it is admitted we must be content to share this trade, because she will always enjoy a certain portion of it in defiance of our efforts; but from a country of such vast extent and whose productions are so various and of such incalculable amount, there will be sufficient trade to sustain both New Orleans and Baltimore; and we may feel fully contented if we can succeed in securing to ourselves that portion of it which will prefer to seek a market east of the mountains.

"Of the several artificial means which human ingenuity and industry have devised to open easy and economical communications between distant points, turnpike roads, canals and railroads have unquestionably the advantage over all others. When turnpike roads were first attempted in England they were almost universally opposed by the great body of people; a few enterprising citizens, however, succeeded after a severe struggle in constructing them. The amount of traveling was then so limited that this means of transportation was found abundantly sufficient for all the exigencies of the then trade of that country; in a little time, however, so great was the increase of commerce there (and which increase in a great measure resulted from the advantages these roads afforded) that even the turnpike in a short time was found insufficient to accommodate the growing trade of the country, and the substitution of canals in place of roads was the consequence, in every situation where the construction of them was practicable.

"It was soon ascertained that in proportion to the increased facilities afforded to trade by the canals in England, was the increase of trade itself, until even this means of communication was actually, in many of the more commercial parts of the country, found insufficient for the transportation required.

"Railroads had, upon a limited scale, been used in several places in England and Wales for a number of years, and had, in every instance, been found fully to answer the purposes required, as far as the experiment had been made. The idea of applying them on a more extended scale appears, however, only recently to have been suggested in that country, but notwithstanding so little time has elapsed since the attempt was first made, yet we find that so decided have been the advantages over turn-pike roads and even over canals, that already 2000 miles of them are actually completed or in a train of rapid progress in Great Britain, and that the experiment of their construction has not in one case failed, nor has there been one instance in which

they have not fully answered the most sanguine expectations of their projectors. Indeed, so completely has this improvement succeeded in England, that it is the opinion of many judicious and practical men there, that these roads will, for heavy transportation, supersede canals as effectively as canals have superseded turnpike roads."

Further in this report it is stated that with the facilities afforded by the proposed Baltimore and Ohio Railroad, many articles, particularly foodstuffs, would not only bear transportation to Baltimore, but would furnish a constantly increasing supply of freight on the proposed road, and become a source of great wealth to the people of the West.

Illustrating the truth of this assertion, a barrel of flour commanding $5 in Baltimore would not, as an article of export to that market, be worth more than $1 at Wheeling on the Ohio River, the cost of transportation being estimated at $4. On the proposed railroad, however, the rate from the Ohio River to Baltimore was estimated at $10 per ton, making the cost of carrying a barrel of flour only $1. Thus at once its value as an article of export would be enhanced in Ohio from $1 to $4 a barrel.

The expense of conveying cotton upon the proposed railroad from the Ohio River to Baltimore, including all charges, was estimated at 1/4 cent a pound, certainly not more than 1/2 cent a pound; and coal from the Allegheny Mountains near Cumberland, including its cost at the pits, could be delivered at Baltimore for 11 to 12 cents a bushel, or about $3 a ton.

These rates were the beginning of rate-making in America. Briefly, the rate today on a ton of coal from Cumberland has decreased from $3 to $1.18 per ton or 61 percent. The rate on flour has decreased from $1 to 30c a barrel or 70 percent, and on cotton from five mills to 1.8 mills a pound or 64 percent.

The report then proceeded to show the advantages that canals had in England over a similar system of transportation in this country on account of the milder climate and the absence of danger from stagnation of water. Although the facts in the possession of the Committee with regard to the railroad system were not as extensive as desired, its members gleaned enough from the documents to leave no doubt in their minds that a railroad was better adapted to the physical conditions than a

canal across the mountains. They therefore recommended that measures be taken to "construct a double railroad between the City of Baltimore and some suitable point upon the Ohio River by the most eligible and direct route, and that a charter to incorporate a company to execute the work be obtained as early as possible."

The report was unanimously adopted by the meeting and a large edition of it ordered published in pamphlet form. It was further resolved that immediate application be made to the Legislature of Maryland for an Act incorporating a joint stock company to be styled "The Baltimore and Ohio Railroad Company."

Fig. 2. The "First Stone."

It was further resolved that capital stock of the Company would be $5 000 000. Steps were taken to get a charter through the Legislature of Maryland. It was the first railroad charter obtained in the United States and is a rare document, particularly in that it indicated its author's remarkable perception and appreciation at that early period of the powers that would

be required by such a corporation. The author of the document was J. V. L. McMahon, an eminent lawyer of Baltimore. The charter was duly granted and at the same session of the Legislature in 1828 an additional Bill was passed authorizing the State of Maryland to subscribe $500 000 in stock in the Baltimore and Ohio Railroad Company, which was the first Legislative aid offered to a railroad in the United States.

Construction of the road was commenced July 4, 1828, accompanied by one of the most magnificent processions of military and civic associations, trades and professions, ever witnessed in the United States. The "First Stone" was laid at Mt. Clare, Baltimore, by the venerable Charles Carroll, of Carrollton, then over 90 years of age. After he had performed this service, addressing himself to one of his friends he said: "I consider this among the most important acts of my life, second only to the signing of the Declaration of Independence, even if indeed it be second to that."

The "First Stone," shown by Fig. 2, was lost for many years on account of changes in the line and grade of the railroad. In 1898, after the stone had been lost for over 50 years, surveys were made and it was located and raised from its original setting. It is now protected and in a good state of preservation and will mark the beginning of the great American railroad transportation systems for many generations to come.

It was desired to build the railroad to the Potomac at the earliest possible date so as to transport the tidewater coal that was being floated down the river. The laying of rails began in the fall of 1829, and these were laid upon wooden sleepers at the east end of Mt. Clare premises, at which point a passenger station was erected shortly after and is still standing. The first division of the road was opened for transportation of passengers on May 22, 1830, it being a little more than 18 months after the commencement of the work. Horse and mule power was used to haul the cars. Locomotives at this period were in their infancy and until the opening of the Liverpool and Manchester Railroad in England, during the same year, the utmost speed obtained in travel by locomotives did not exceed 6 miles an hour.

NOTES ON EARLY OPERATION

There were many extremely interesting incidents in connection with the promotion and development of such a revolutionary idea as the building of a railroad, and before the road had more than started demands were made by the people for a ride over the iron rails which they saw being laid. Probably something over 20 miles of the grading had been finished and the rails had been laid at least as far as Ellicott Mills, 13 miles from Baltimore, when, as stated by a Baltimore paper, in answer to a popular demand, a "BRIGADE OF CARS" would run a regular schedule between those points. The first brigade of cars, the type of which is shown by Fig. 3, was drawn by one horse, and it is recorded that Charles Carroll of Carrollton and some of the city officials were passengers in the car "Pioneer," which was used on that occasion.

This operation by horses between Baltimore and Ellicott Mills was continued for some time, but it developed that this could not always be the means of locomotion for a railroad.

Another interesting idea was to mount sails on the cars and procure propulsion by means of the wind. This, however, was doomed to failure.

After this period and during the early trials of several locomotives which were then invented for hauling cars on iron rails, the historical race took place between Peter Cooper's engine, the "Tom Thumb," and a horse drawn vehicle in the regular operation of the stage line between Baltimore and Relay.

The present Baltimore and Ohio passenger station at Relay was a tavern in the early days and people frequently drove from Baltimore to have dinner at this hostelry, which was famous for its cuisine. It was on the return trip of Peter Cooper's "Tom Thumb" from Ellicott Mills that it was met by the horse and vehicle at Relay and a race proposed to Baltimore. Soon after the race had begun it was seen that the locomotive was easily winning from the horse and it is recorded that the driver was just about to pull up and acknowledge himself beaten by the new steam engine when the apparatus working the blower on the "Tom Thumb" got out of order; without the draft the steam went down in the boiler, Mr. Cooper was entirely unable to work the blower by hand and the horse

forged ahead and won the race. This is probably the first locomotive steam failure on record in the United States.

CLASH WITH CANAL COMPANY AT HARPERS FERRY

It is well known that the first lines of transportation were over National Pikes constructed in the early days, notably that from Cumberland, Maryland, to Steubenville, Ohio. Later there followed a general development of canals, due, in all probability, to the high cost of transportation by roads. The greatest agitation in regard to the building of canals occurred early in

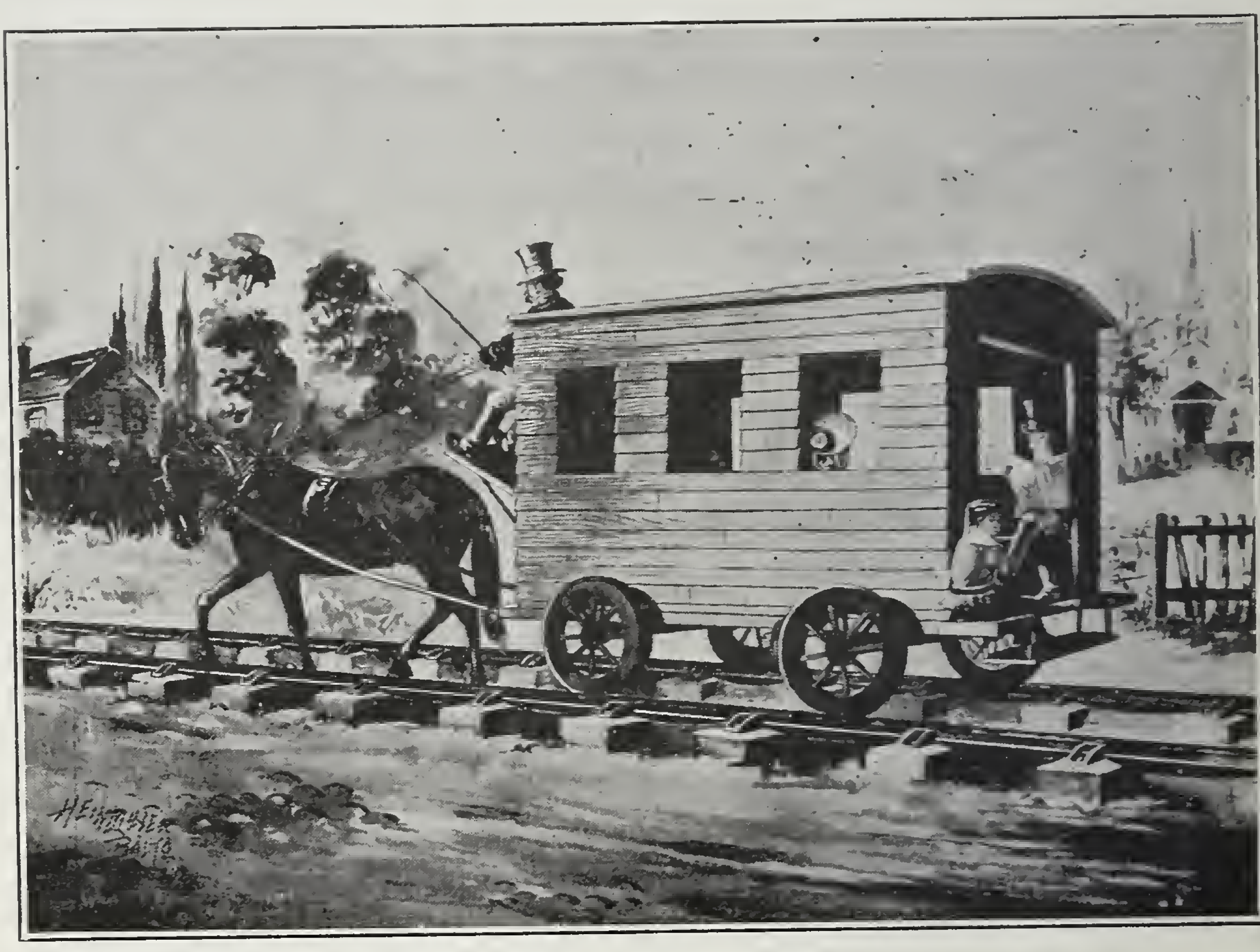


Fig. 3. First Passenger Car.

the first few decades of the nineteenth century, and in our particular locality the Chesapeake and Ohio Canal was considered to be a project which would forever insure the prosperity of the City of Baltimore. It had been one of Washington's particular schemes, as he had often considered that the Potomac Valley offered a good route for a canal.

After the idea of railroads began to develop and had taken some definite form in the beginning of the construction of the Baltimore and Ohio, there were controversies between the interests building the canal and those building the railroad,

the canal people believing that the Potomac Valley was too narrow for the location of both the railroad and the waterway. It was claimed that the noise from the engines would scare the horses, and it finally culminated in an injunction being secured by the canal interests against the railroad. The Canal Company insisted that the Railroad Company should build a fence between its road and the canal in order to prevent the tow horses from being frightened by the engines and the railroad had to agree to haul its trains by horses over the sections where the canal and the railroad were close together. At Harpers Ferry the canal and railroad were very near each other and it was at this point that trouble first arose between the two companies.

In 1832 the Court of Appeals of Maryland decided the cases of injunction in favor of the Canal Company and prevented the Railroad Company from appropriating or using land for the railroad until the Canal Company had located its route between Point of Rocks and Harpers Ferry. A commission was appointed to adjust the matter and it made a very convincing report to Congress.

In 1833 a Bill was passed based upon the conclusions of this commission which brought the troubles to a close. The Railroad Company paid the Canal Company $266 000 for all claims under a compromise act in which the Canal Company was to construct the railroad as well as the canal between Point of Rocks and Harpers Ferry, and this portion of the road was completed December 1, 1834.

It was in the territory between Brunswick, Harpers Ferry and Cumberland that so many incidents of interest relative to the Civil War were enacted.

FINANCIAL TROUBLES

The financial difficulties which were encountered during both the early and later construction of the railroad almost caused the abandonment of the project. The promoters started out with free right of way and due to the glowing prospects the stock was over subscribed. During the year 1828, the State of Maryland made its first subscription to the stock of the road, amounting to $500 000. Individual subscriptions during the

year amounted to $1 500 000, and at the end of 1828 the entire capital had reached about $4 000 000. However this soon disappeared in the construction of the road, the cost having been underestimated by the engineers, and the directors of the Railroad Company realized that they would have to proceed with the work upon their own resources. The President and several of the directors advanced a total of $200 000 and under the direction of President Thomas these difficulties were gradually met.

Owing to the stringency in the money market during 1839

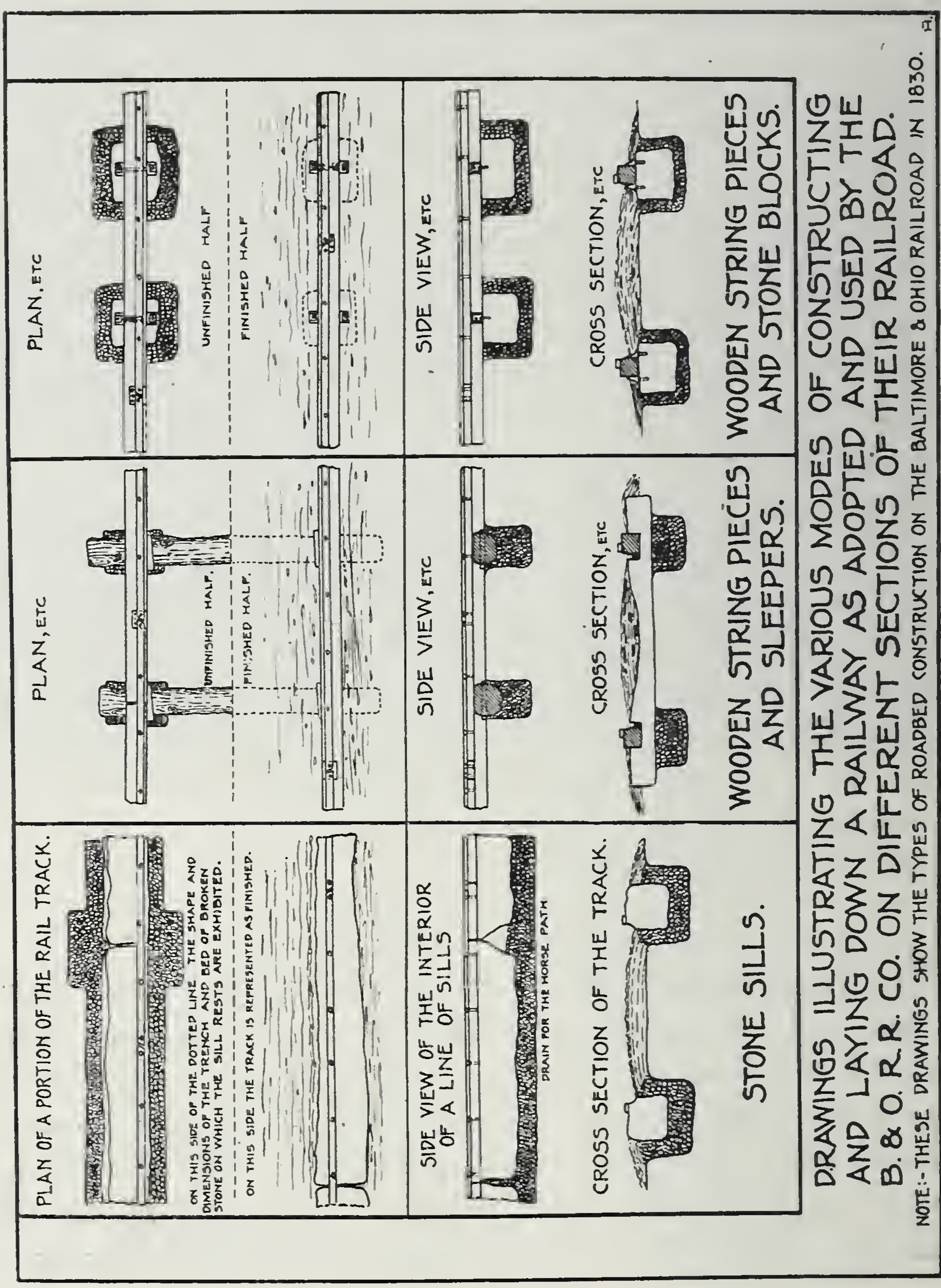


Fig. 4. Types of Early Roadbed Construction.

and 1840, the work of building the line west of Cumberland was suspended. In 1848, Thomas Swann was elected President of the Baltimore and Ohio Railroad Company and the records at that time show that the shares had fallen to 28 cents on the dollar.

Notwithstanding the great depreciation in the value of the shares, the City of Baltimore found that its original subscriptions of $3 500 000 had been more than returned in the increased value of real estate, the increase in population and the general growth which were almost directly traceable to the construction of the railroad.

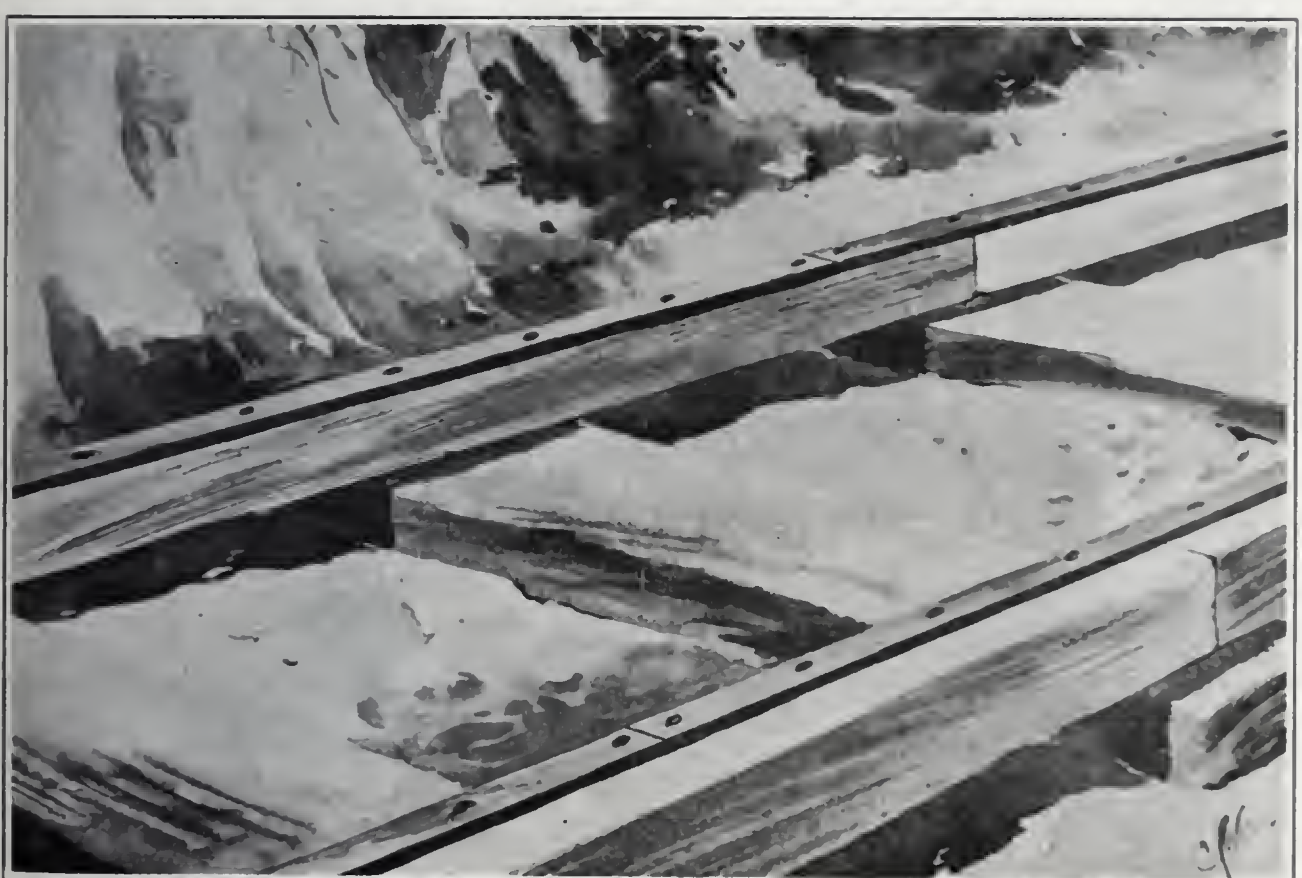


Fig. 5. Strap Rail Track Construction.

Much money was needed, and in 1851 the disbursements of the road amounted to $200 000 per month for construction.

A crisis now arose in President Swann's administration taxing his ability to overcome it. He laid a betterment plan before the Directors and secured their approval, and after repeated efforts, coupon bonds were sold at home and abroad at 80. The report of October, 1852, gives an idea of the troubles through which the road was passing. This report shows that during that time, for the construction of the road west of Cum-

berland there had been expended $7 271 732 for approximately 200 miles of line then nearing completion, or an average of $36 360 a mile. Compared with construction work in 1852, we have today the Magnolia Cut-Off, approximately 12 miles of double track line costing $6 000 000, or $500 000 a mile.

On June 22, 1852, the road was formally opened to the town of Fairmont on the Monongahela River, 71 miles east of Wheeling. In 1851 President Swann had promised to stand with his guests, from the City of Baltimore and the States of Virginia and Maryland, on the banks of the Ohio at Wheeling on the first day of January, 1853, and this was literally realized.

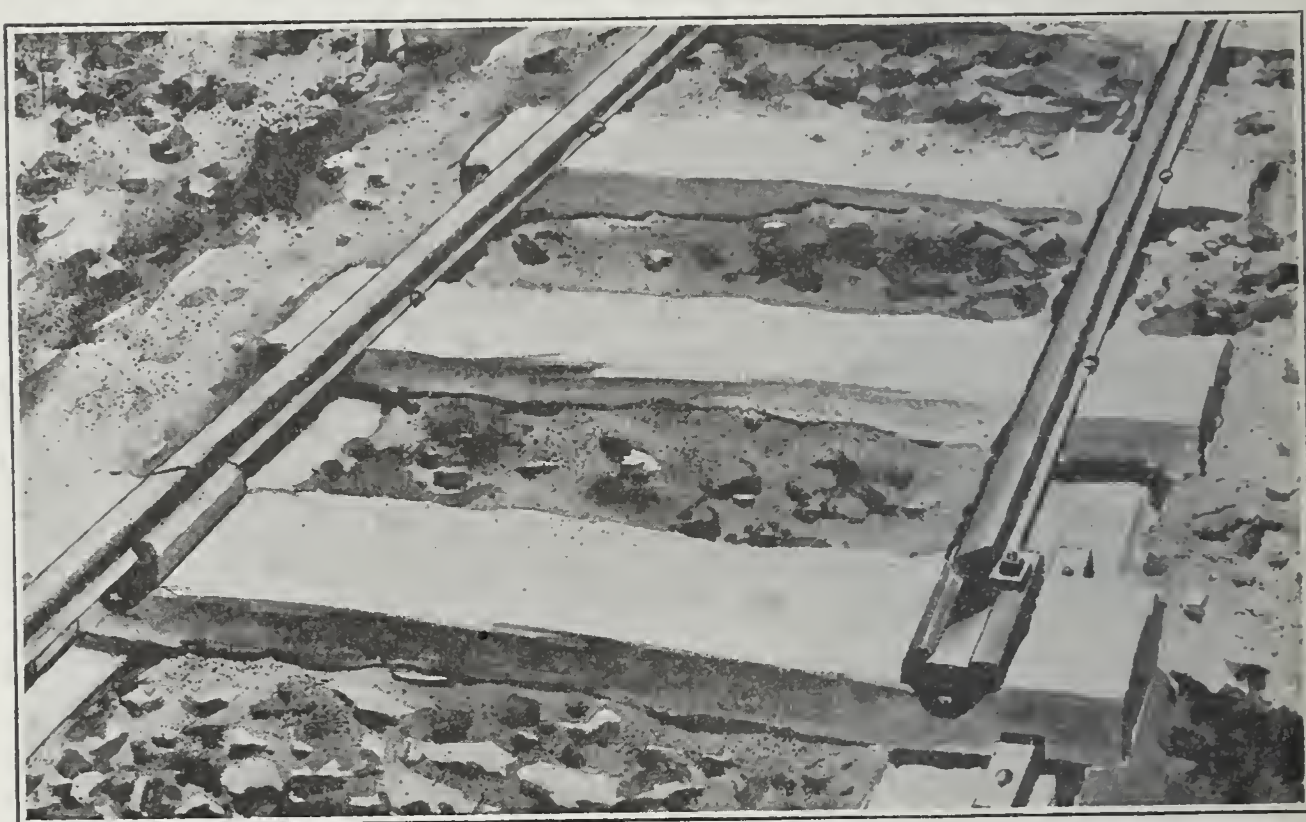


Fig. 6. First "T" Rail Design.

The closing remarks in President Swann's Annual Report for 1853 announcing the consummation of this undertaking are worth special notice, as there runs through them a thread of thought clearly indicating the financial difficulties under which he had labored during his regime as President of the road. President Swann wrote:

It is now 26 years since the Baltimore and Ohio Railroad Company made their first annual report to the enterprising stockholders, by whose capital and public spirit this Board was called into being. Of those who stood prominent in the early organization, few have survived the delay which has attended the progress of this road, or

will be present to rejoice with us in the work of final completion. In the animating prospects of the future, it becomes us, however, not to forget what is due to those who have borne a part in the conception of the grand idea which it embodies. History will do justice to the past as well as the present.

"After years of delay, surrounded by embarrassments, and staggering under the vastness of the undertaking—with a credit almost exhausted—its few remaining friends scattered and disheartened—a community over-taxed—and an opposition rendered formidable by the honesty of the convictions under which they acted—this great work entered upon its extension from Cumberland to the city of Wheeling, a distance of more than 200 miles. Through every vicissitude of climate, obstructed by interminable rocks, or opposed by a succession of mountain barriers, altogether without a parallel in the progress of similar enterprises, by day and by night, it has passed forward in such a march as human labor is seldom called to encounter, sustained only by that determined spirit which so strongly marks the character of the age in which we live; until it is now within reach of the goal for which it has so long been striving."

DEVELOPMENT OF ROADBED

A brief description of the construction of the first track is very interesting, the following by the late Major J. G. Pangborn of the Baltimore and Ohio being taken from "The World's Rail Way":

"After the ground is brought to a level, square holes are dug 4 ft. apart, 20 in. wide, 2 ft. long and 2 ft. deep. These holes are filled level full of broken stones securely rammed down. After the foundation is thus made, a trench 6 in. deep is dug connecting each hole with the opposite. These trenches are also filled with stones and upon them cedar sleepers, or cross pieces are placed with great care and accuracy, a spirit level being used to adjust them properly. In each of these cross pieces, immediately above the stone foundation notches are cut and into these the wooden rail stringers are carefully leveled and secured by wedges. These stringers are of yellow pine and from 20 to 24 ft. long, 6 in. square and beveled on top to clear the flanges of the wheels, which are on the outside, not the inside as on some lines. On the top of the stringers the iron rails are carefully nailed with wrought iron nails 4 in. long.

"This method of construction was used on the first seven and a quarter miles, to Vinegar Hill, at a cost of $4002 per mile. West of Vinegar Hill, long granite slabs were substituted for the cedar cross pieces and yellow pine stringers for a distance of six and three-quarter miles at a cost of $5116 a mile to Ellicott Mills, to which point the track was completed May, 1831."

The early specifications would indicate that the gauge at that time was either the present standard—4 ft. 8½ in.—or very near it. The strap rails were not successful, it having been found that traffic would loosen and turn them up as the wheels passed over, forming what was called "snake heads," which sometimes rose up and punched holes through the car floors.

Figs. 4 and 5 show the type of early roadbed and track construction.

The road was completed to Point of Rocks, 73 miles west

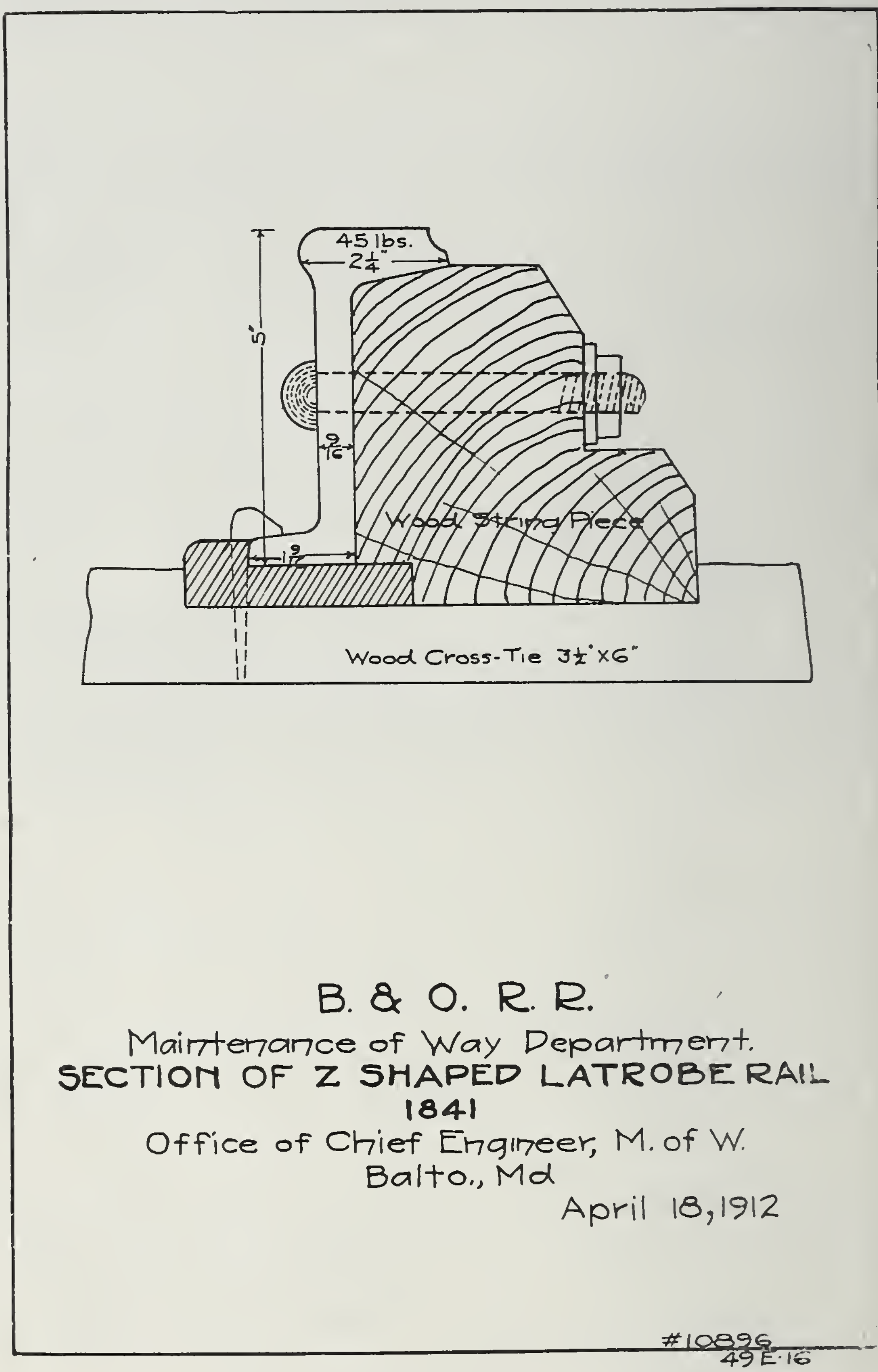


Fig. 7. Section of "Z" Rail.

of Baltimore, in 1832, several methods of construction having been pursued. Stone was used for track to the head of the Patapsco; from there to Point of Rocks it was not available, therefore timber was used. Forty miles of line were on granite sills 8 in. thick, 15 in. wide and various lengths laid in trenches filled with broken stone. Thirty-three miles of road had various forms of construction: Wood and iron rails on stone block; wood and iron rails supported by broken stone; wood and iron rails supported by longitudinal ground sills instead of broken stone: and log rails formed of trunks of trees worked to a surface on one side to receive the iron and supported by wooden sleepers.

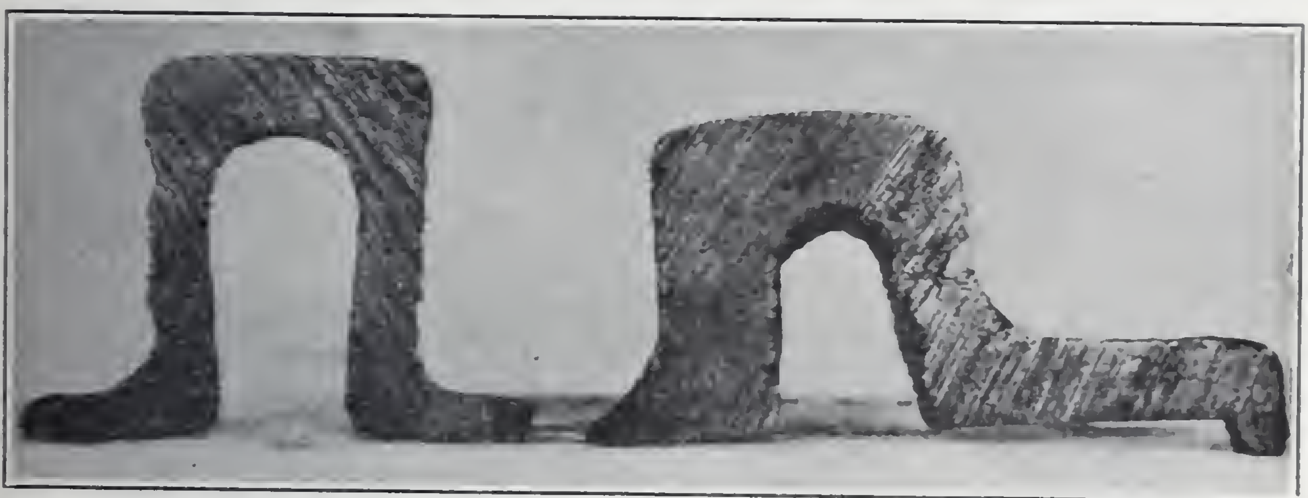


Fig. 8. "U" Type Rail Design.

The *"T"* rail as we know it, was designed about 1830 by R. L. Stevens, President and Chief Engineer of the Camden and Amboy Railroad; he also devised the "hook headed" spike and the "iron tongue" which has developed into the fish plate or angle bar. The *"T"* rail was first manufactured in England.

The first *"T"* rail on the Baltimore and Ohio was placed on the Washington Branch, which was completed in 1834. This rail weighed 40 lb. to the yard and the ends were cut at an angle of 60 deg., as shown by Fig. 6.

In 1841 B. H. Latrobe of Baltimore designed a "Z" bar rail, Fig. 7, for the Baltimore and Ohio. This was a compound rail of wood and iron and weighed 45 lb. to the yard.

The first rail rolled in America was the product of the Mt. Savage Rolling Mill, Allegany County, Maryland. This rail. Fig. 8, was the *"U"* type and weighed 40 lb. to the yard and

was often called bridge rail because it was the first rail laid on cross ties instead of longitudinal stringers.

The period of greatest importance in the history of rail was between 1847 and 1857, during which time the Bessemer process for making steel was perfected.

The Baltimore and Ohio constructed a rolling mill at Cumberland, Maryland, 1869-1871, and rolled the pear shaped rail section. The mill cost $548 000 and was in continuous operation until 1890, when it was leased to the Cambria Iron Company. Fig. 9 illustrates the section of rail rolled at the Cumberland Mill.

Fig. 9. Pear Shaped Rail Section.

After the close of the Civil War a great many rail sections came into use. It was estimated that in 1880 the mills carried rolls for 300 different rail sections. The Baltimore and Ohio was no exception in regard to the use of various rail sections, which did not become generally standardized until 1893.

In 1887 the American Society of Civil Engineers appointed a committee to consider "the proper relation to each other of the sections of rails and wheels." This committee reported in 1893 and submitted a series of sections of rail weighing from 40 lb. to 100 lb. to the yard, varying in intervals of 5 lb. These sections were adopted by the Society and promulgated as the A. S. C. E. standard sections, many of which were used by the Baltimore and Ohio Railroad.

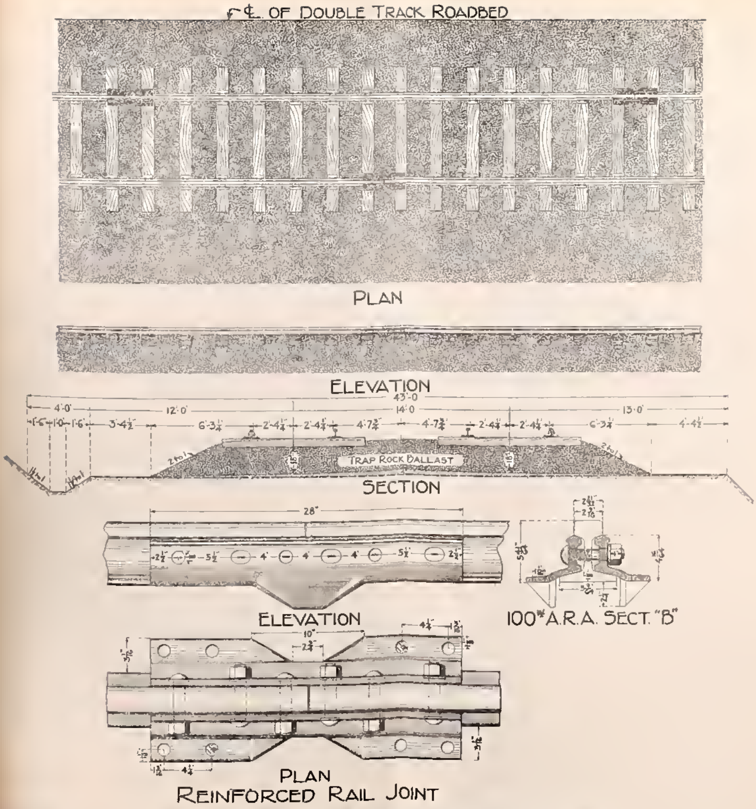


Fig. 10. Type of Roadbed and Rail Section Used on the Magnolia Cut-Off.

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In 1901 it was thought that the steel rails in use were not giving satisfaction. The consequent agitation resulted in the sections recommended by the American Railway Association and known as the A. R. A. sections. In 1908 the Baltimore and Ohio purchased for test purposes 4 100 tons of 90 lb. rail rolled to conform to the A. R. A. sections and since 1909 all rail purchased has been A. R. A. sections except 3 000 tons of A. S. C. E. The next important step in the advance of rail is the present gradual but sure change from bessemer to the more serviceable open hearth steel.

In the United States there may be found today many different types of roadbed construction which in general are all constructed on one basic principle. The rails are spiked and held to gauge, 4 ft. 8½ in., by cross ties spaced from 18 in. to 24 in. center to center. The rail section and weight is usually determined by the local conditions and volume of traffic as well as the nature of the roadbed. The track may be placed on natural, or earth, ballast if the traffic is light or it may be put on cinder, gravel, slag or stone ballast.

Broken stone is generally considered the best form of ballast for heavy traffic lines and may be placed under the ties to a depth varying between 6 in. and 2 ft. Fig. 10 illustrates the type of roadbed construction and rail section used on the Magnolia Cut-Off Improvement. Trap rock ballast, 18 in. deep, was used with 100 lb. A. R. A. section "*B*" rail with reinforced or truss rail joints.

DEVELOPMENT OF THE LOCOMOTIVE

The first American locomotive found to be of service was introduced by Phineas Davis in 1831 as the result of a competition in which a prize of $4 000 was offered for the best design of locomotive that would conform to certain specifications. Davis' engine was known as the "York," Fig. 11, and was built at York, Pennsylvania. It was mounted on 30 in. wheels for common cars and weighed 3½ tons. It was found capable of conveying 15 tons at the rate of about 15 miles an hour on level track. The "York" was operated between Baltimore and Ellicott Mills, a distance of 13 miles, taking about one hour to make the trip.

As a matter of record and interest, a few of the points are noted in connection with the specifications of the first locomotive, which were issued by the President of the railroad. The locomotive was to be of American make and for which the Railroad Company would pay $4 000.

"It must burn coke or coal and must consume its own smoke.

"When in operation it must not exceed 3½ tons in weight and must be capable of drawing day by day 15 tons, inclusive of weight of the wagons, 15 miles per hour on a level road. The Company will

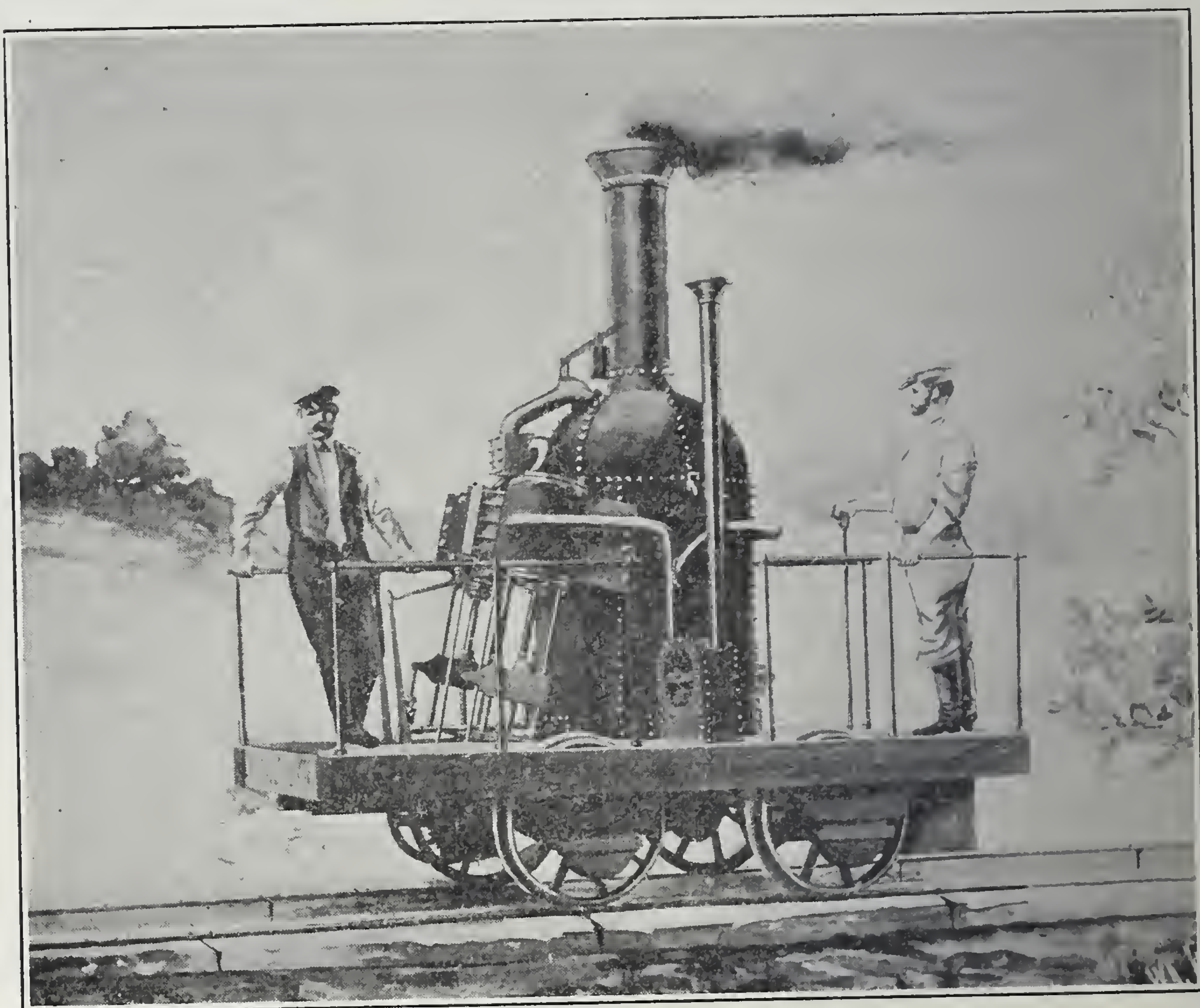

Fig. 11. The "York" Locomotive.

furnish wagons of Winans' construction, the friction of which will not exceed 5 lb. to the ton.

"In deciding on the relative advantages of the several engines, the Company will take into consideration their respective weights, power and durability and all other things being equal, give preference to the engine weighing the least.

"The flanges are to run on the inside of the rails. The form of the cone and flanges and the tread of the wheels must be such as are now in use on the road. If the working parts are so connected as to work with the adhesion of all four wheels, then all the wheels shall

be of equal diameter not to exceed 3 ft.; but if the connection be such as to work with the adhesion of two wheels only, then those two wheels may have a diameter not exceeding 4 ft., and the other two wheels shall be 2½ ft. in diameter and shall work with Winans' friction wheels, which last will be furnished on application to the Company. The flanges to be 4 ft. 7½ in. apart from outside to outside. The wheels to be coupled 4 ft. from center to center in order to suit curves of short radius.

"The pressure of the steam must not exceed 100 lb. to the square inch; and as a less pressure will be preferred, the Company in deciding

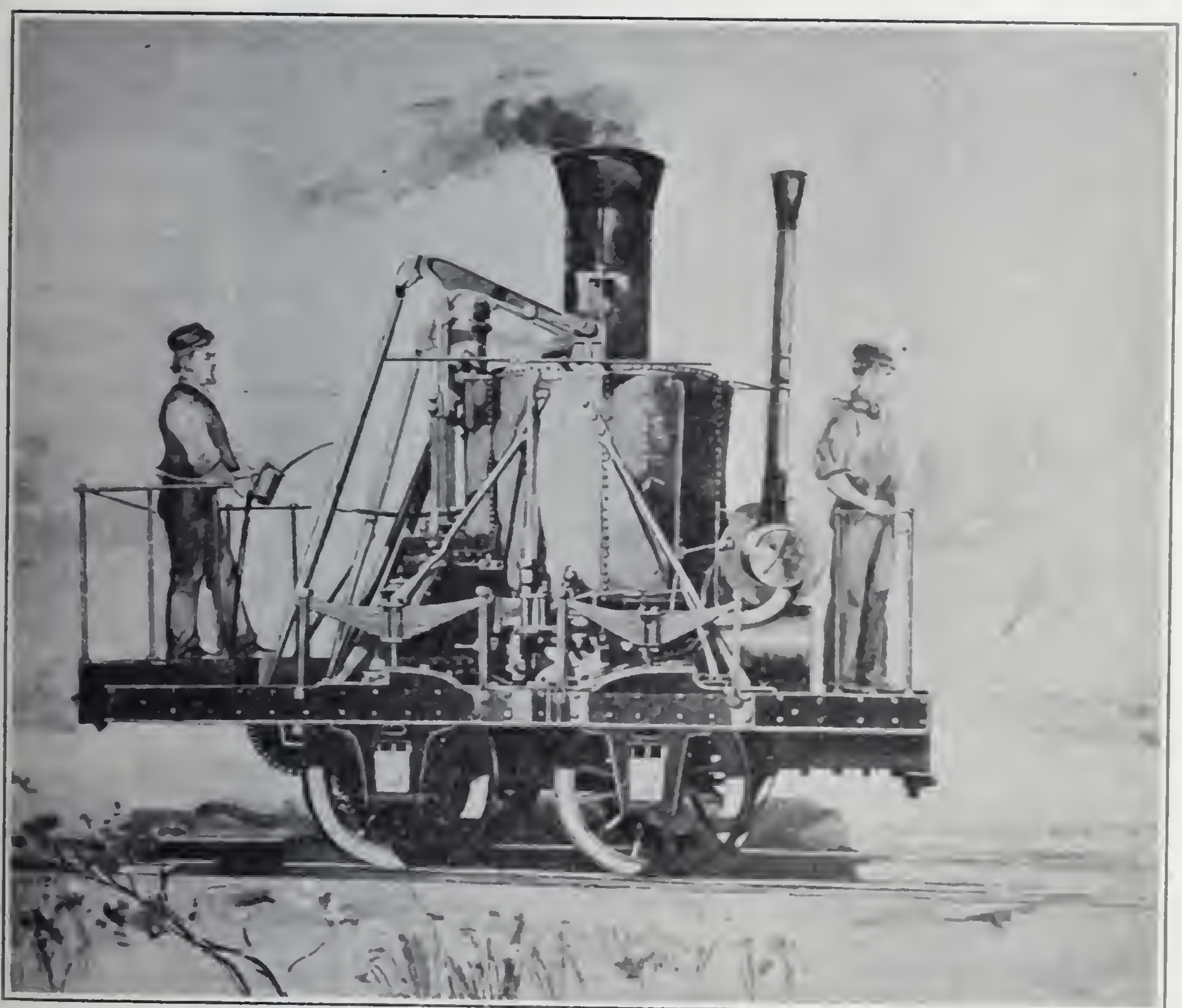

Fig. 12. The "Atlantic" Locomotive.

on the advantages of the several engines will take into consideration their relative degrees of pressure. The Company will be at liberty to put the boiler, fire tube, cylinder, etc., to the test of a pressure of water not exceeding three times the pressure of the steam intended to be worked, without being answerable for any damage to the machine which it may receive in consequence of such test.

"There must be two safety valves, one of which must be completely out of reach or control of the engineman, and neither of which must be fastened down while the engine is working.

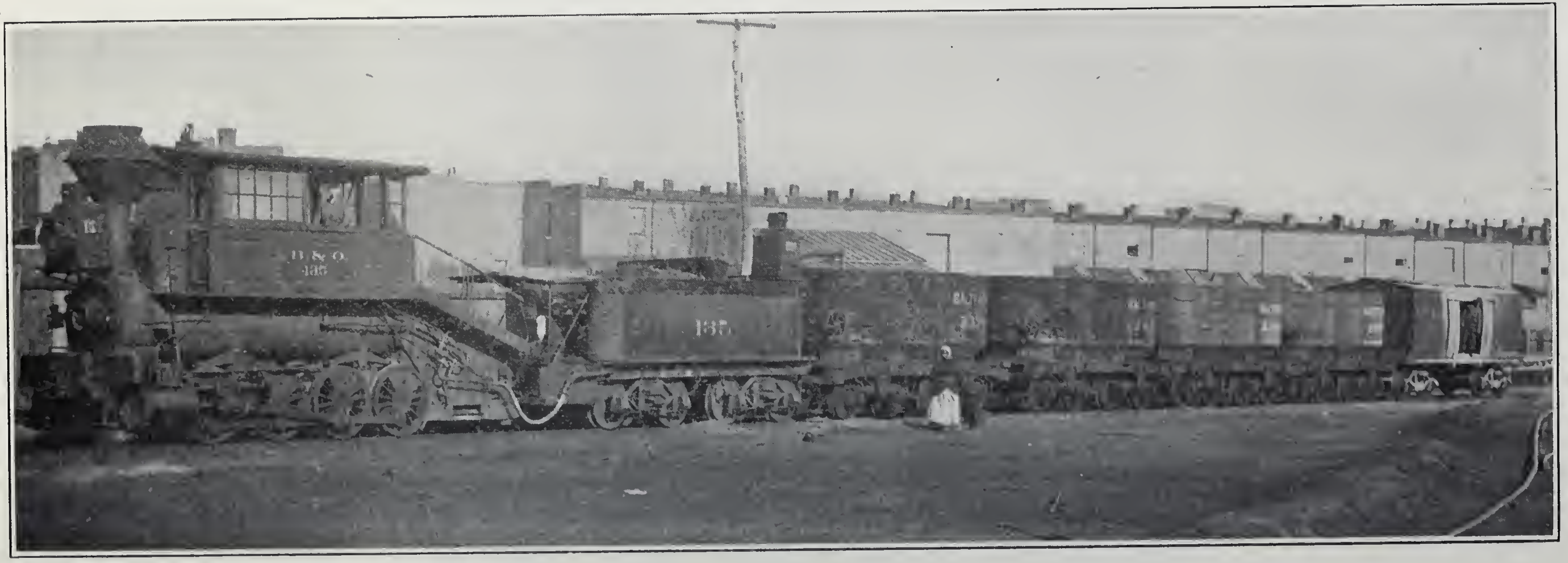

Fig. 13. The "Camelback" Locomotive and Early Type of Iron Hopper Cars.

"The engine and boiler must be supported on springs and rest on four wheels, and the height from the ground to the top of the chimney must not exceed 12 ft.

"There must be a mercurial gauge affixed to the machine with an index rod, showing the steam pressure above 50 lb. per sq. in. and constructed to blow out at 100 lb. pressure.

"The engine which may appear to offer the greatest advantages will be subject to the performance of 30 days' regular work on the road at the end of which time, if they shall have proved durable and continue to be capable of performing agreeably to their first exhibition, as aforesaid, they will be received and paid for as here stipulated.

P. E. THOMAS,
President.

"N. B. The Railroad Company will provide and will furnish a tender and supply of water and fuel for trial. Persons desirous of examining the road or of obtaining more minute information are invited to address themselves to the President of the Company. The least radius of curvature of the road is 400 ft.—14 deg. 30 min. curve. Competitors who arrive with their engines before the first of June will be allowed to make experiments on the road previous to that day.

"The Editors of the National Gazette, Philadelphia, Commercial Advertiser, New York, and Pittsburgh Statesman, will copy the above once a week for four weeks, and forward their bills to the Baltimore and Ohio Railroad Company."

The next machine introduced in the development of the locomotive was the engine given the name "Atlantic," Fig. 12, built in 1832. This engine weighed 6½ tons and was capable of pulling five cars weighing about 18 tons at the rate of 12 miles an hour. The "Atlantic" had two upright cylinders 10 in. in diameter with a 20 in. stroke. Power was transmitted by gearing to the driving axle through pinions so that one double stroke of the piston would cause two revolutions of the driving wheels, which were 30 in. in diameter. This period marks the beginning of the remarkable development in the construction and power of railroad locomotives.

The photograph, Fig. 13, made in 1897 may be of interest and shows the old "Camelback" locomotive and four iron hopper cars which were used for hauling coal and lime in bulk. The "Camelback" locomotive No. 135 was about the last of its type. These old cars were constructed during the period 1883 to 1893 at a cost of approximately $400. They weighed from 12 800 to 25 600 lb. and had a carrying capacity of 13 to 25

Fig. 14. The Mikado Locomotive.

tons. The box car at the end of this train was built of steel and was one of the first experiments in the construction of all steel freight cars.

At the close of the year 1835 there were 7 locomotives, 44 coaches and 1 078 freight cars in use. At the end of the fiscal year 1914, or 79 years later, there were 2365 locomotives, 1292 passenger coaches of all kinds and 88 055 freight cars exclusive of work train equipment.

The Mikado Locomotive, Fig. 14, is used in road service on the East End of the Cumberland Division and other divisions of the Baltimore and Ohio Railroad. By its introduction many economies in transportation have been effected. It weighs 232 tons including tender and has a tractive power of 54 600 lb.

The heaviest type of road locomotive in through freight service today on the Baltimore and Ohio is the Class *S* or "Centipede" shown by Fig. 15. This engine, including tender, weighs 293 tons and has a length of 87 ft. over all. There are two cylinders 30 in. in diameter, 32 in. stroke and five sets of 50 in. driving wheels; it has a tractive power of 84 000 lb. and will draw 7300 tons ascending a 0.3 percent grade or a train of 100 cars each carrying 50 tons. The largest engine in the Baltimore and Ohio service is the Mallet, Fig. 16, and weighs 321 tons including tender. It has a tractive power of 105 000 lb. and a length of 93 ft. over all. There are two 26 in. and two 41 in. cylinders having 32 in. stroke. Each pair of cylinders is connected with four driving axles having a total of 16 wheels, 56 in. in diameter. The Baltimore and Ohio was the first railroad in America to use the Mallet type of locomotive, the earliest one having been built in 1904 by the American Locomotive Company. The total weight of this locomotive and tender is 176 tons; the tractive power 71 500 lb.; the total length 79 ft. 5 in.; diameter of cylinders 32 in. and 20 in. by 32 in. stroke. Each pair of cylinders is connected to three driving axles having 12 wheels 56 in. in diameter. It will be noted that the weight and power of this type of engine has been largely increased. The Mallet engines are now used as helpers on some of the heavy mountain grades.

The Erie Railroad Triple *E* Type, Fig. 17, is the latest design of heavy locomotive. It was built by the Baldwin Loco-

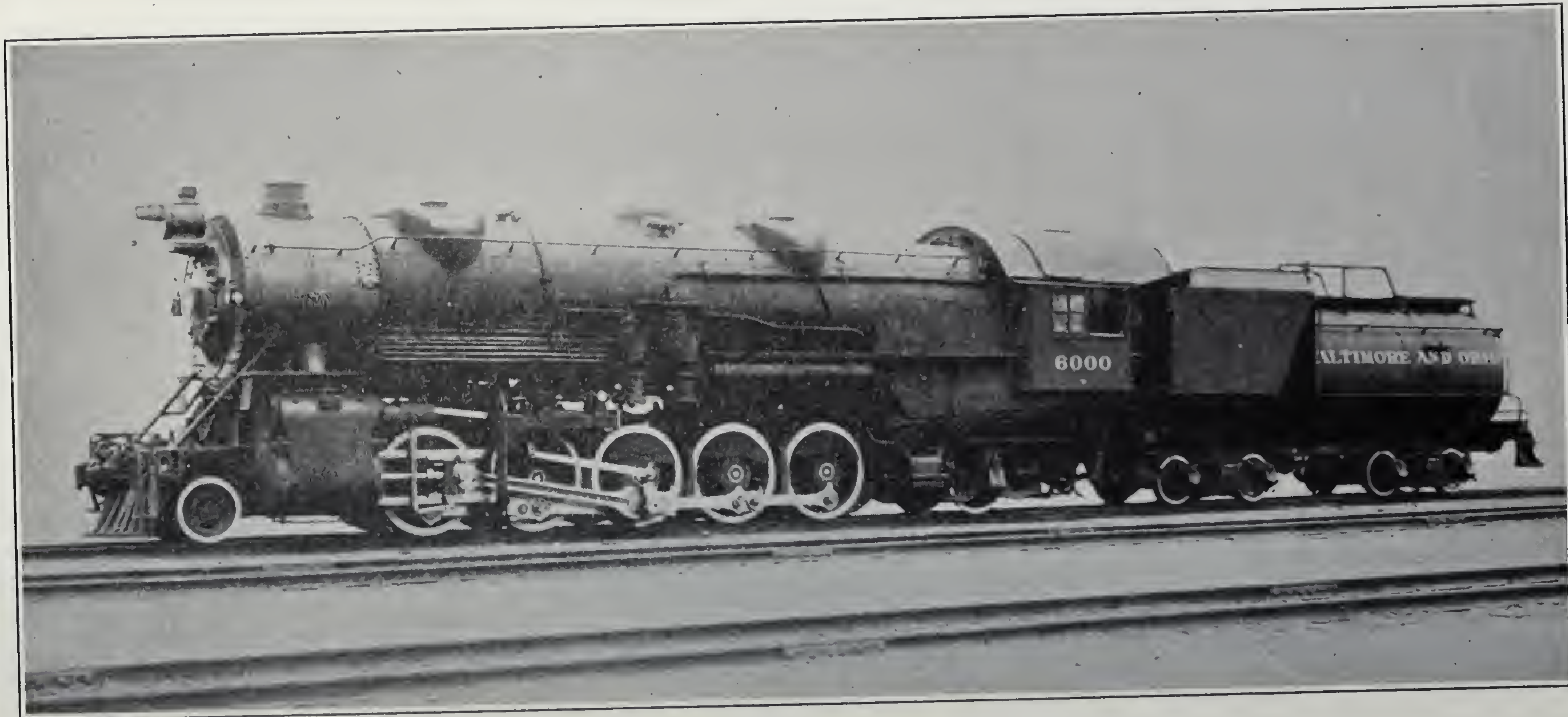

Fig. 15. The Class "S" or "Centipede" Locomo tive.

motive Works and tested on the Philadelphia Division of the Baltimore and Ohio Railroad. The engine has a total weight, including tender, of 422 tons, with tractive power of 160 000 lb. The length from base of truck wheel to base of tank trailer wheel is 90 ft., making the total length over all more than 100 ft. There are two high pressure and four low pressure cylinders, 36 in. diameter and 32 in. stroke. Each pair of cylinders is connected to four driving axles having a total of 24 wheels 56 in. in diameter. Eight of the driving wheels are located under the tender.

A comparison of the principal dimensions, weights and capacities, etc., of the B. & O. Mikado, Centipede, Mallet and the Erie Triple *"E"* Type—Matt H. Shay—locomotives is shown in Table No. 1.

TABLE NO. 1

COMPARISON OF LOCOMOTIVES

	B. & O. Mikado 2-8-2	B. & O. Centipede 2-10-2	B. & O. Mallet 0-8-8-0	ERIE Matt H. Shay 2-8-8-8-2
Cylinders				
High Pressure	26″ × 32″	30″ × 32″	2— 26″ × 32″	2— 36″ × 32″
Low Pressure			2— 41″ × 32″	4— 36″ × 32″
Boiler				
Diameter	78″	90″	90″	94″
Working Pressure	190 lb.	200 lb.	210 lb.	210 lb.
Heating Surface				
Total	3970 sq. ft.	5573 sq. ft.	5541 sq. ft.	6886 sq. ft.
Driving Wheels				
Diameter Center	56″	50″	56″	56″
Wheel Base				
Driving	16′ 9″	21′ 0″	40′ 8″	71′ 6″
Rigid	16′ 9″	21′ 0″	15′ 0″	16′ 6″
Total Engine	35′ 0″	40′ 3″	40′ 8″	
Total Engine & Tender	71′ 2⅝″	76′ 6″	77′ 2¾″	90′ 0″
Tank				
Water Capacity	9500 gal.	10 000 gal.	9500 gal.	10 000 gal.
Coal Capacity	16 tons	16 tons	16 tons	16 tons
Weight				
On all driving wheels	222 000 lb.	336 800 lb.	461 000 lb.	753 600 lb.
Total Engine & Tender	460 000 lb.	584 000 lb.	642 500 lb.	845 050 lb.
Tractive Power	54 600 lb.	84 000 lb.	105 000 lb.	160 000 lb.

DEVELOPMENT OF THE FREIGHT CAR

The first cars placed on the railroad and drawn by horses could be likened to the small cars now used in construction work. They were capable of carrying about two tons. The four wheels 30 in. in diameter were made to run on grooved wooden rails, laid on stone sills. This method was soon superseded by

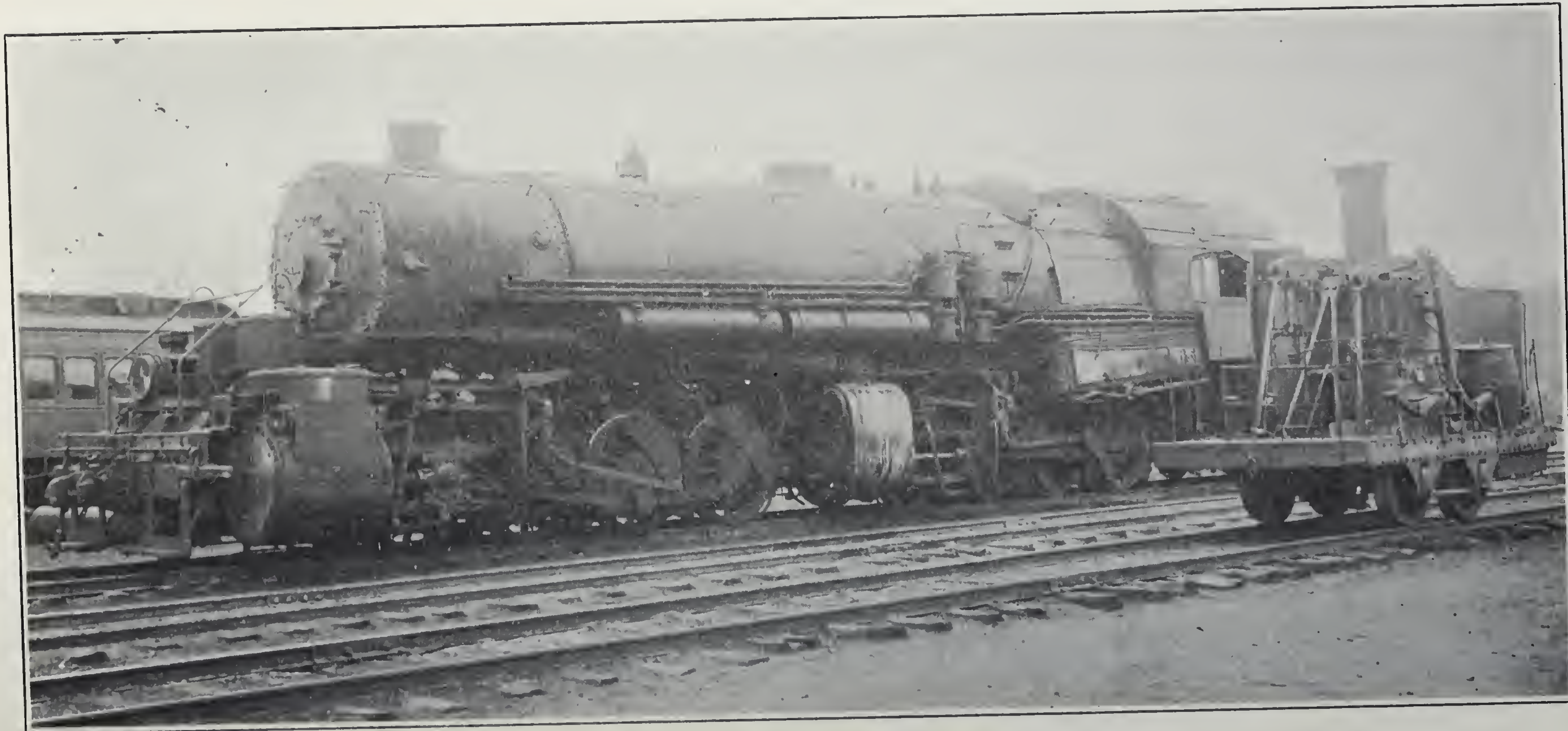

Fig. 16. The Mallet Locomotive and "Atlantic" Locomotive.

wheels having flanges on the outside which were run on iron straps that were spiked to the wooden sills. At about the same time other experiments were made and wheels were developed with flanges on the inside which were run on the iron straps having the inside lines to gauge. Fig. 18 shows a line drawing of the early freight car designed for carrying flour between Ellicott Mills, where flour mills were located to utilize the water power of the Patapsco River, and Baltimore, 13 miles.

Soon after the operation of the road it became evident that a closed car would be necessary for the protection of freight and passengers from the elements and the box car and the passenger coach were developed. These cars were of light wooden construction and instead of four wheels they were placed on two sets of trucks having four wheels each. The Ross Winans passenger coach, Fig. 19, was run on the first railroad in 1832.

The size and capacity of the freight car grew with the increased traffic and expansion of the railroad. In 1902 the average capacity of the freight car on the Baltimore and Ohio was about 29 tons; today it is 42 tons, an increase of 45 percent in 12 years. The largest freight car of today is a steel coal car, having 12 wheels and a carrying capacity of 100 tons, used by the Norfolk & Western Railway.

GROWTH OF THE BALTIMORE AND OHIO

It is interesting to note Table No. 2, showing the miles of road operated, gross earnings and earnings per mile of road in the early days as compared with the present time, and it indicates the wonderfully rapid growth which has taken place.

TABLE NO. 2

COMPARISON OF EARNINGS

Year	*Mileage*	*Gross Earnings*	*Per Mile*
1831	13	$31 405	$2 416
1834	72	205 436	2 853
1844	210	870 809	4 147
1854	410	4 014 839	9 792
1864	514	10 138 876	19 725
1874	1011	14 947 090	14 785
1884	1711	19 436 607	11 360
1894	2065	22 502 062	10 897
1904	3987	65 071 081	16 321
1913	4456	101 556 131	22 791

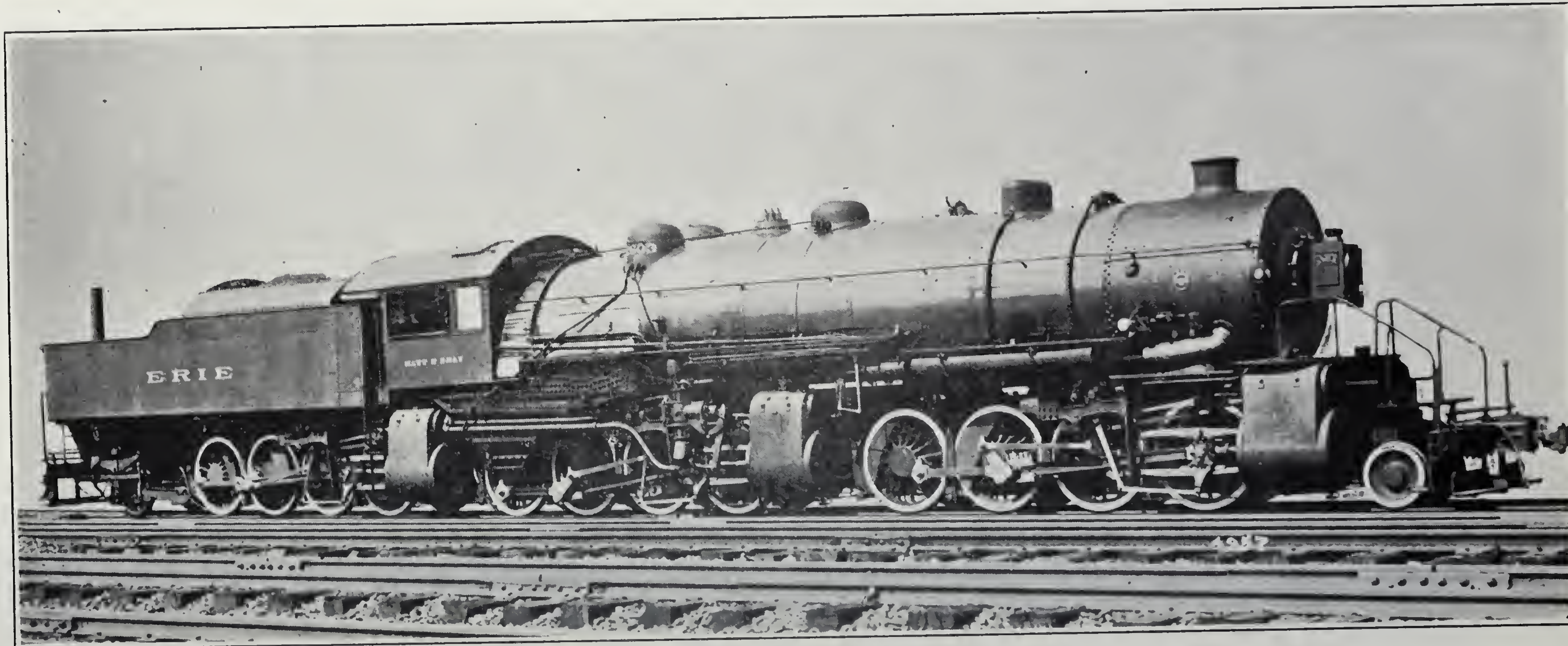

Fig. 17. The Erie Railroad Triple "E" Type Locomotive.
The "Matt H. Shay."

The capital investment in the Baltimore and Ohio Railroad in 1832 was less than \$4 000 000, which included large damage expenditures paid to the Chesapeake and Ohio Canal Company. The total capital investment of the Baltimore and Ohio in 1913, including stocks, bonds and other securities, aggregated over \$700 000 000.

The mileage of railroads operated in the United States now is over 249 900, the total gross annual revenue being nearly \$3 000 000 000. The number of employes actually engaged in railroad work in the United States now is more than 1 500 000, whose wages amount to \$1 250 000 000 yearly.

THESE DEVELOPMENTS WITHIN MEMORY OF ONE MAN NOW LIVING

There is living in Cumberland, Maryland, the first agent of the Baltimore and Ohio at that point, Judge Oliver Gephart. In company with his father he attended the laying of the cornerstone of the Baltimore and Ohio at Mt. Clare, Baltimore, and remarked at the time that it was his desire to reach the age of Charles Carroll of Carrollton, who was then past 90. Mr. Gephart is now past 96 years of age, is in full possession of all his faculties and his reminiscences are extremely interesting. He worked on the grading of the canal near Cumberland, and associated himself with the Baltimore and Ohio in its early days.

While serving as ticket agent at Cumberland he studied law, was admitted to the Maryland Bar and later became Judge of the Orphans' Court. He is a very well-known and influential citizen of Cumberland and takes a keen interest in everything pertaining to his home city. He is a director of the Second National Bank, one of the strongest banks in the State of Maryland, and for 39 years has attended the directors' meetings regularly.

Thus within the memory of one man, or over a period of 80 years, the American railroad transportation machine has developed from stage coach to steel passenger train. Out of the old stage coach days and the period of early railroading Judge Gephart has passed to our time with its fast engines, dining cars and automobiles to meet them. It is now possible for him to travel in one day, surrounded by comforts undreamed of, a distance which would have required a week in his boyhood.

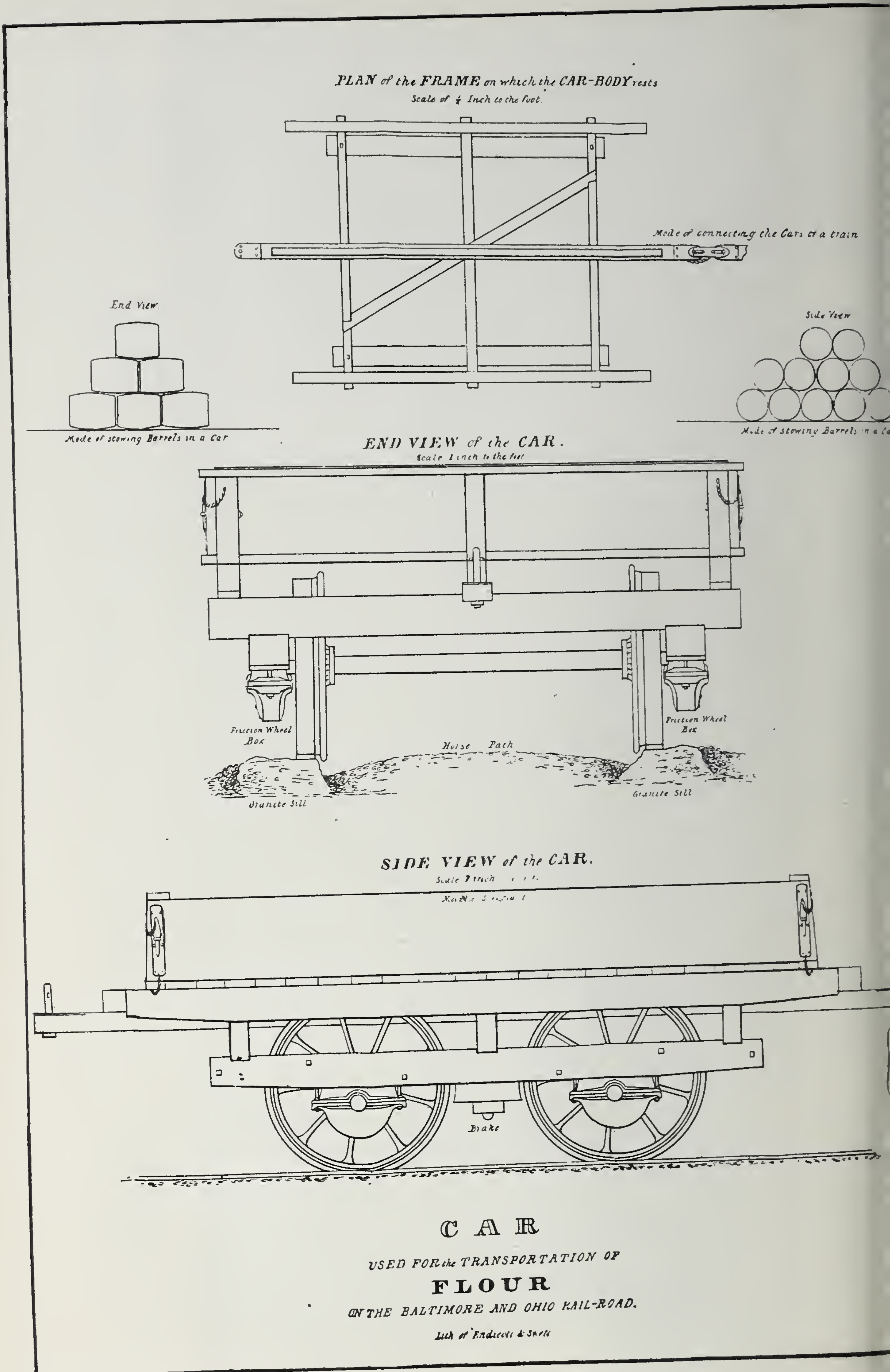

Fig. 18. Early Freight Car Design.

EARLY DESIGNS OF BRIDGE TRUSSES

It may be of interest to remark that Messrs. Wendell Bollman and Albert Fink, the designers of trusses bearing their names, were at one time employes of the Baltimore and Ohio. A good example of the Bollman truss exists today in the highway bridge crossing the Potomac River at Harpers Ferry. The Bollman truss consists of a series of hollow tubes connected from the tops of the end posts to each panel point of the lower chord,

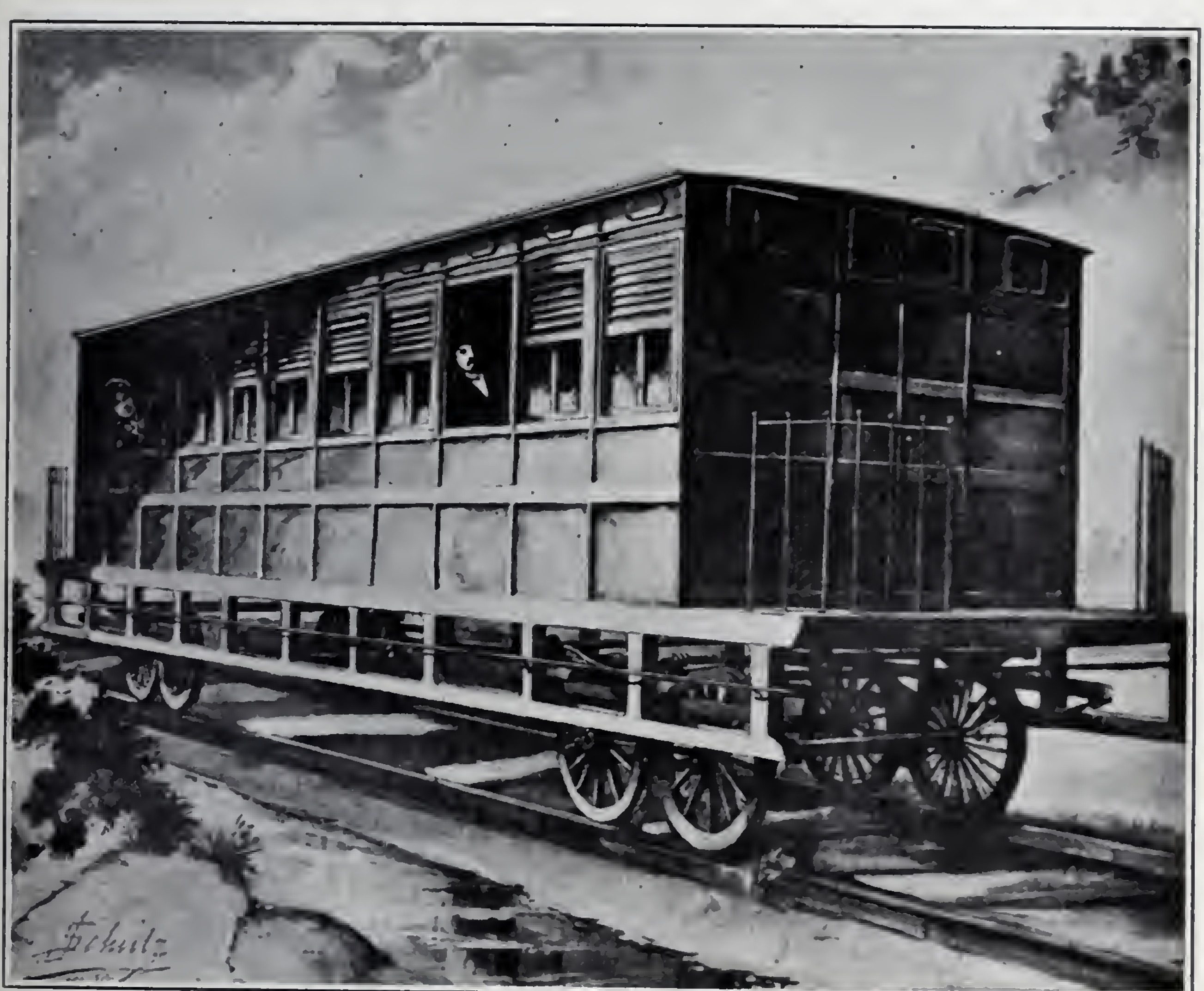

Fig. 19. The Ross Winans Passenger Coach.

and is so designed that every point on the panel is self-supporting and can be removed for repairs without disturbing any other member. Fig. 20 shows a single span Bollman truss bridge, in use at the present time on the Pulp Mill Spur of the Baltimore and Ohio at Harpers Ferry. Fink was employed as a draftsman in the Mt. Clare Shops. He became very much interested in the Bollman design and developed what is known as the Fink truss, which was considered an improvement on the former. As you know, the Fink truss is used on many highways and in

some instances by railroads. He also designed the roof trusses now in use in the Mt. Clare, Martinsburg and Grafton roundhouses.

HISTORICAL RAILROAD COLLECTION

The Baltimore and Ohio has preserved a large collection of historical locomotives, track fixtures, cars and records which was exhibited at the World's Fair at Chicago in 1893, and at the Louisiana Purchase Exposition at St. Louis in 1904. This exhibit is stored in a large building of the Company at Martinsburg, W. Va., and may be examined by any one caring to go there. It consists in general of about 15 original and 45 full sized wooden models showing the development of early locomotives. There are examples of the early freight cars and passenger coaches and about 2200 pictures of all kinds of vehicles used in various parts of the world, including an ox cart that was in service 2300 years ago. All stages of the development of transportation and motive power, beginning with Sir Isaac Newton's "Idea", early in the eighteenth century, up to the present time are covered by the collection.

SURVEYS AND CONSTRUCTION OF LINE

EARLY SURVEYS

Some interesting facts in connection with the early surveys point to the unusual care and extreme accuracy taken by the Engineers in their work. The maps were elaborate and much care was given to the topographical work. It seems, in fact, that more time than necessary was used in compiling notes and maps, particularly with reference to their lettering and titles.

Various routes were surveyed from Baltimore to the Ohio River, many of which would not have been necessary had general maps been available. So little was known of the country, however, that divers routes were followed, some of which proved to be impracticable.

As an evidence of the thoroughness of the work of the early engineers it might be said that in recent studies made for changes in grade and alignment, reference to the original surveys disclosed the fact that practically every feasible line had been studied, but the line decided upon generally had been adopted because of the lower cost of construction.

Fig. 20. A Bollman Truss Bridge.

PLANES CROSSING PARRS RIDGE AND ROUTE VIA MT. AIRY

One of the most interesting features in connection with the early surveys was the route over the first summit west from Baltimore known as Parrs Ridge. It being thought that locomotives could not be used on grades exceeding 27½ ft. to the mile, a system of planes with stationary engines at the tops was designed to carry the cars over the summits. On the map and profile, Fig. 21, are shown the three locations of the line over Parrs Ridge. First, there is the system of planes, the grades of which varied from 3.1 to 4.9 percent. Second, is shown the circuitous route, via Mt. Airy, established in 1839, the maximum grade of which was 1.5 percent. Third, is shown the Mt. Airy cut-off completed in 1902, which follows closely the original line of planes, and has a tunnel 2700 ft. long near the summit.

Plane No. 1 was approached from the east by an ascending 0.74 percent grade to the foot of the incline, 636 ft. above sea level, at which point the grade ascends on tangent at the rate of 3.1 percent to an elevation of 716 ft. At the summit of Plane No. 1 there is a level grade for a distance of about 3300 ft., the alignment of which is practically a compound reverse curve 3 deg. to 2 deg. left and 11 deg. right.

Plane No. 2 ascends from the 716 ft. level to the summit of the mountain, 828 ft. in elevation. This incline is on tangent and has a 3.3 percent ascending grade. The line on the west side of the mountain descends to the 576 ft. level through two inclines, Nos. 3 and 4.

Plane No. 3 is on tangent and has grade of 4.9 percent descending 172 ft. to the 656 ft. level. This was the longest and steepest grade over the mountain. At the foot of Plane No. 3 there is a level section of the old line about 3 600 ft. in length the alignment of which includes three curves, 9 deg. 30 min. left, 5 deg. right and 14 deg. left.

Plane No. 4 descends from the 656 ft. elevation to 576 ft. The grade is about 3.6 percent. An inspection of the old line indicates there was considerable excavation, especially on the planes. Traces of the old roadbed are easily followed for the entire length of line except at points covered by the construction of the Mt. Airy Tunnel Line.

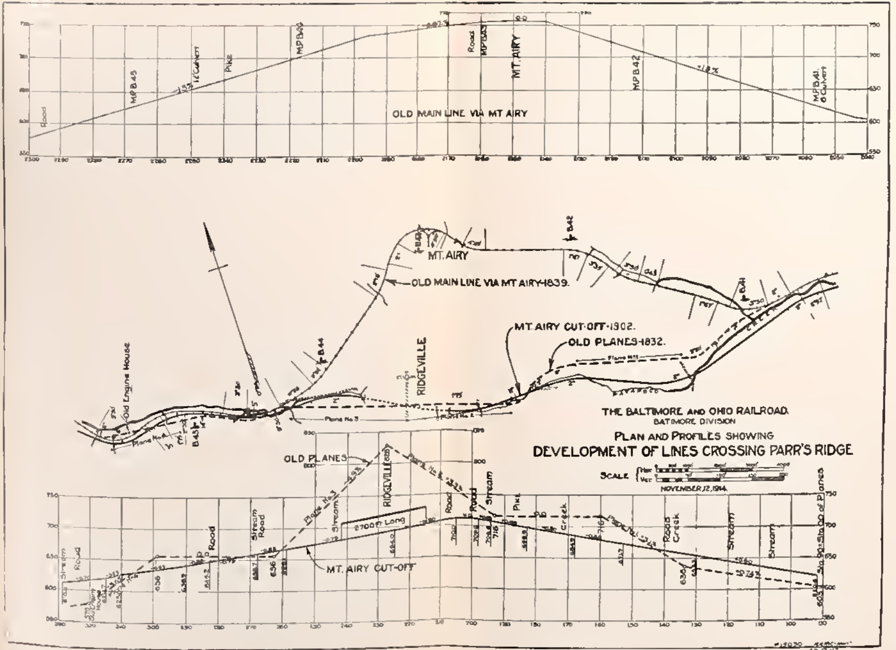

Fig. 21. The Three Lines Crossing Parrs Ridge.

The inclined planes were located for stationary engines which were used together with horses in operating the section of line crossing Parrs Ridge. It was on these planes that the first tests were made, by the Chief Engineers, to determine what grade a locomotive could overcome. Based somewhat on the results of these experiments, trunk lines were later built in the West with grades from 3 to 4 percent.

By the abandonment of the planes in 1839 and the establishment of a line by way of Mt. Airy with a maximum grade of 1.5 percent, a saving in operation of $20 000 per year was effected, and the time of freight trains between Harpers Ferry and Baltimore was reduced 48 hours. This line increased the distance about 4600 ft. and has been in continuous operation since first opened.

MT. AIRY CUT-OFF

On February 28, 1900, and April 4, 1901, the Board of Directors authorized the expenditure of $1 137 286 for the construction of a new line over the mountain known as the Mt. Airy Cut-Off. Surveys were completed and the line constructed along the route, paralleling, crossing and recrossing the line of the old planes. The summit, about 710 ft. above sea-level, is reached by a maximum 0.88 percent grade. A two-track tunnel 2700 ft. in length was constructed through the mountain, the east portal of which is about 1000 ft. from the summit of the line. The Mt. Airy Cut-Off was completed in August, 1902, and marked a decided improvement. The grades were lowered, compared with the old line via Mt. Airy, from 1½ percent to about 0.88 percent compensated. A saving of 4860 ft. in distance and 449 deg. in curvature resulted. The cost was $1 310 819.

The sketch map, Fig. 21, indicates three steps of railroad development:

1. The location of inclined planes across the mountain in 1832 operated by stationary engines and ropes, when it was thought that a grade greater than 27½ ft. to the mile would not be practical for the steam locomotive.

2. After it was determined that the operation of the steam locomotive was practical on heavier grades, the circuitous route through a gap near Mt. Airy was constructed, having a maxi-

mum grade of 80 ft. to the mile, thus doing away with the inclined planes and the heavy expense of their operation.

3. The construction of a shorter low grade line by a tunnel through Parrs Ridge summit, thus decreasing the cost of operation by permitting larger train loading, less curvature and distance.

This is one of the best examples in development of railroad location which has ever come under my notice. The original line with the planes was built over the lowest summit, and because of the heavy grade stationary engines were used to haul the cars over the ridge.

To do away with the planes, development was made using distance to reduce grade. Finally, with the improved machinery for handling excavation, a return to the location near the planes was made and a tunnel constructed at the summit. This indicates clearly how the theory and practice of railroad location developed.

SURVEYS FROM HARPERS FERRY TO CUMBERLAND AND BEYOND

Details of the studies covering a period of 17 years, of the proposed routes from Harpers Ferry to Cumberland and over the mountains to the Ohio River, are very interesting. Many routes were surveyed between Harpers Ferry and Cumberland, in which territory the Magnolia Cut-Off Improvement is located. The present line, which was the one adopted, follows in a circuitious route the south bank of the Potomac River from Cherry Run to Cumberland, a distance of 62 miles.

The work beyond Harpers Ferry was arrested on account of a clause in the compromise of 1832 with the Canal Company relative to the Point of Rocks. This clause bound the Railroad Company not to attempt to ascend the Potomac beyond Harpers Ferry until the canal should be completed to Cumberland, provided this be done in the time allowed by the existing charter of the Canal Company. This agreement necessitated crossing the river to West Virginia at Harpers Ferry and the crossing back into Maryland near Cumberland. It was also agreed that in consideration of financial assistance from the Virginia Legislature, the railroad should be constructed in Vir-

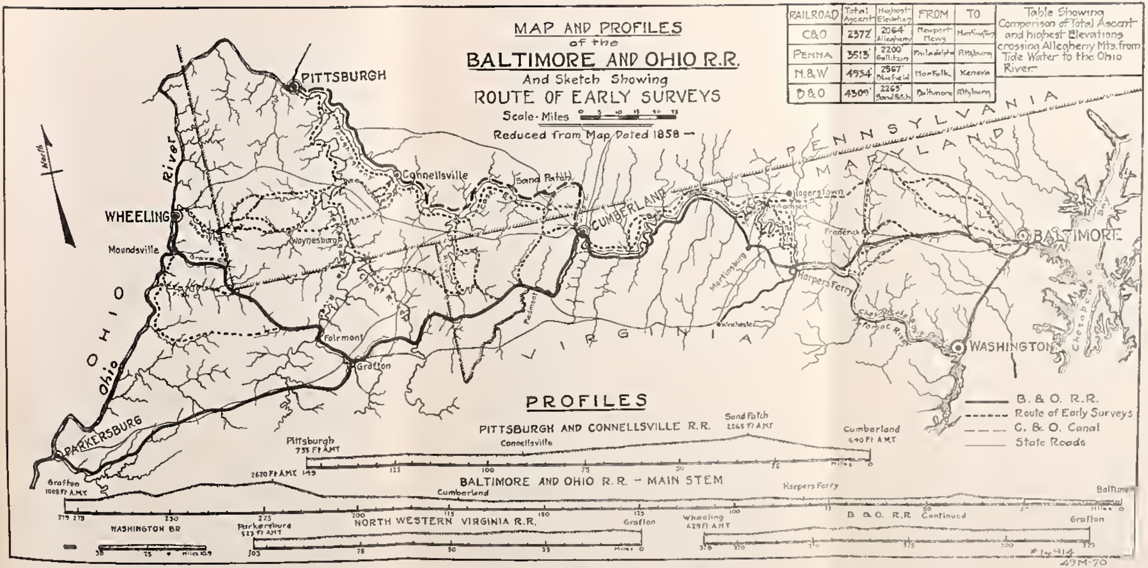

Fig. 22. The B. & O. R. R. in 1858 and Routes of Early Surveys.

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ginia. This agreement was made previous to the formation of West Virginia as a sovereign state.

Preliminary surveys from Harpers Ferry to the Ohio River together with estimate of cost were prepared by Benjamin H. Latrobe in 1838. A satisfactory route to the Ohio River, embracing both Wheeling and Pittsburgh, was established at a maximum grade of 66 ft. to the mile, the estimated cost of construction for a single track from Cumberland to the Ohio River, a distance of 200 miles, being $9 500 000, or $47 500 per mile.

The Maryland Legislature of 1835-1836 removed the restrictions in connection with the Chesapeake and Ohio Canal project, thus permitting the construction of the railroad to be carried forward more rapidly. In the spring of 1836 vigorous measures were taken to extend the road westward from Harpers Ferry and an engineering force was organized for making detailed surveys and examinations between Harpers Ferry and the summit of the Allegheny Mountains with a view of pushing the railroad through to Wheeling and Pittsburgh.

Under instructions given by Philip E. Thomas, President of the Baltimore and Ohio Railroad, Benjamin H. Latrobe was appointed to the position of Engineer of Location and Construction on July 1, 1836, and took immediate charge of the engineering work in the mountainous country over which the surveys had to be carried. The importance of leaving unexamined no practical route of the many that had presented themselves rendered the labors of the engineers necessarily very tedious and prolonged.

Four surveying parties were organized and sent into the field according to the following distribution:

The first party was directed to survey a route between Harpers Ferry and the eastern entrance of the North Mountain pass of the Potomac River on the Maryland side.

The second party had instructions to extend the line up the river on the Maryland side from North Mountain.

The third party was to begin the line at Cumberland and come eastward down the river in Maryland and meet the second party.

The fourth party was directed to start at Cumberland and work westward, surveying routes over the mountains.

Early in the month of July, 1837, the second and third parties completed the preliminary surveys between North Mountain and Cumberland.

After effecting a junction of the lines on the Maryland side of the Potomac, it was intended to survey lines on the Virginia side of the river, between North Mountain and Cumberland; but the unhealthy part of the season in this valley being near at hand, the work was delayed until later in the year. The survey under direction of the first party was closed about August, 1836. It passed from a point near Weverton, a few miles below Harpers Ferry, and thence to North Mountain through Pleasant Valley, Boonsborough and Hagerstown. This party then proceeded to make a survey beginning from a point near Harpers Ferry and pursuing the more level route along the ravine of the Potomac River and Antietam Creek, avoiding the summit encountered upon the route through Pleasant Valley.

The original route as surveyed between Weverton and Cumberland was about 108 miles long, making the total distance between Baltimore and Cumberland 187 miles while the distance over lines as constructed is 177 miles. The line as surveyed through Pleasant Valley had about a 1.0 percent grade and avoided the Chesapeake and Ohio Canal from Weverton to North Mountain, 42 miles, and from the mouth of Fifteen Mile Creek to Oldtown, 19 miles, or a total of 61 miles. This left the distance from North Mountain to Hancock 16 miles, with 15 miles additional to the mouth of Fifteen Mile Creek, as well as 16 miles from Oldtown to Cumberland, making 47 miles in all, situated in the immediate vicinity of the river and often in contact with the line of the canal for a considerable distance.

A summary describing the general characteristics of the route surveyed through the valley of the Potomac from near Harpers Ferry to Cumberland follows:

1. From a point near Harpers Ferry, then the termination of the road, to the Narrows at North Mountain, there were two feasible routes,—one from Weverton by Pleasant Valley, Boonsborough and Hagerstown, 43 miles in length, avoiding the river, and consequently the canal for the whole distance; the other from Harpers Ferry by the valleys of the Potomac and Antietam, 36 miles in length, avoiding contact with the canal

by means of a viaduct over the river at the mouth of Antietam Creek.

2. From the Narrows at North Mountain for a distance of 17 miles to a point 3 miles above Hancock, there was a favorable route along the Maryland shore of the river without much embarrassment from the canal, and making questionable the expediency of crossing the river to avoid it.

3. From the point last noted to the mouth of Fifteen Mile Creek, a distance of 13 miles, the two works would be in frequent contact unless avoided by two or more crossings of the river by the railroad.

4. From the mouth of Fifteen Mile Creek to Oldtown, there were two practical routes, each about 20 miles in length, the one by the river valley occasionally interfering with the canal, and the other by the valleys drained by Fifteen Mile and Town Creeks, cutting across the country north of the river and keeping clear of the canal altogether.

5. From Old Town to Cumberland, 16 miles, the route was confined to the river, but had its choice of the two sides alternately, and if occupying the Maryland shore altogether, was brought into numerous contacts with the canal.

The distance from Weverton to Cumberland was 108½ miles by the Pleasant Valley route and 104½ miles by the Antietam route. The surveys along the Virginia shore of the Potomac having been held up in August, 1836, on account of sickness in the first party, were again carried forward in April, 1837, when a party ran a line up the Virginia shore of the Potomac from Harpers Ferry to the mouth of Antietam Creek, tying in at that point with the line along the Maryland side, surveyed the previous year.

A line was run by way of Elk Run, Tuscarora and Tulisses Branches, passing near Martinsburg, the county seat of Berkeley County, Virginia, and re-entering the Potomac Valley at the North Mountain Narrows. A line was also run following the Winchester and Potomac Railroad from Harpers Ferry to Halltown, 6 miles, and thence 5 miles to the line by Elk Run, noted previously.

In July, 1837, the charter from the State of Virginia lapsed and before attempting to proceed further with the work it was


ALL TRAINS VIA WASHINGTON
BALTIMORE

necessary to make application for the renewal of the charter from that state. A law was passed in 1838 extending the time for completing the work five years, but it deprived the Company of the option of selecting between the routes in the State of Maryland and those in the State of Virginia, between Harpers Ferry and Cumberland. On account of this law the Company was obliged to adopt the Virginia route, entering that state at Harpers Ferry.

There were many conditions which appeared to give a decided preference to the occupation of the Virginia territory between Harpers Ferry and Cumberland among which were the fertile valleys bordering on the tributaries of the Potomac River; the avoidance of any collision with the Chesapeake and Ohio Canal, then far advanced in its construction, and with other works projected as rivals both to the railroad and for the trade of Maryland; and the vastly cheaper work through the State of Virginia which amounted to $2 625 000 in favor of the Virginia line.

The route of the road between Harpers Ferry and Cumberland thus definitely determined, the engineers were promptly organized and the location work was completed in October. Most of the contracts were signed in August and the work commenced in September, 1839.

The work was carried on effectively and completed as far as Hancock, a distance of 41½ miles from Harpers Ferry in June, 1842, and in November of the same year it was opened through to Cumberland, a total distance of 97 miles, and followed in general the line as it exists today.

This route may be described as beginning at Harpers Ferry, passing 30 miles through the valley of Virginia and at some distance from the Potomac, until opposite old Fort Frederick, within 12 miles of Hancock, where it returned to the river. The grades throughout this distance are 40 ft. to the mile and curves have a radius of not less than 1000 ft. The route then follows the bank of the river to Cumberland, cutting off, however, the great bends at Doe Gully and the Paw Paw Ridge. Six miles east of Cumberland it crosses from Virginia into Maryland by a viaduct over the North Branch of the Potomac and reaches the National Road in the eastern margin of the town.

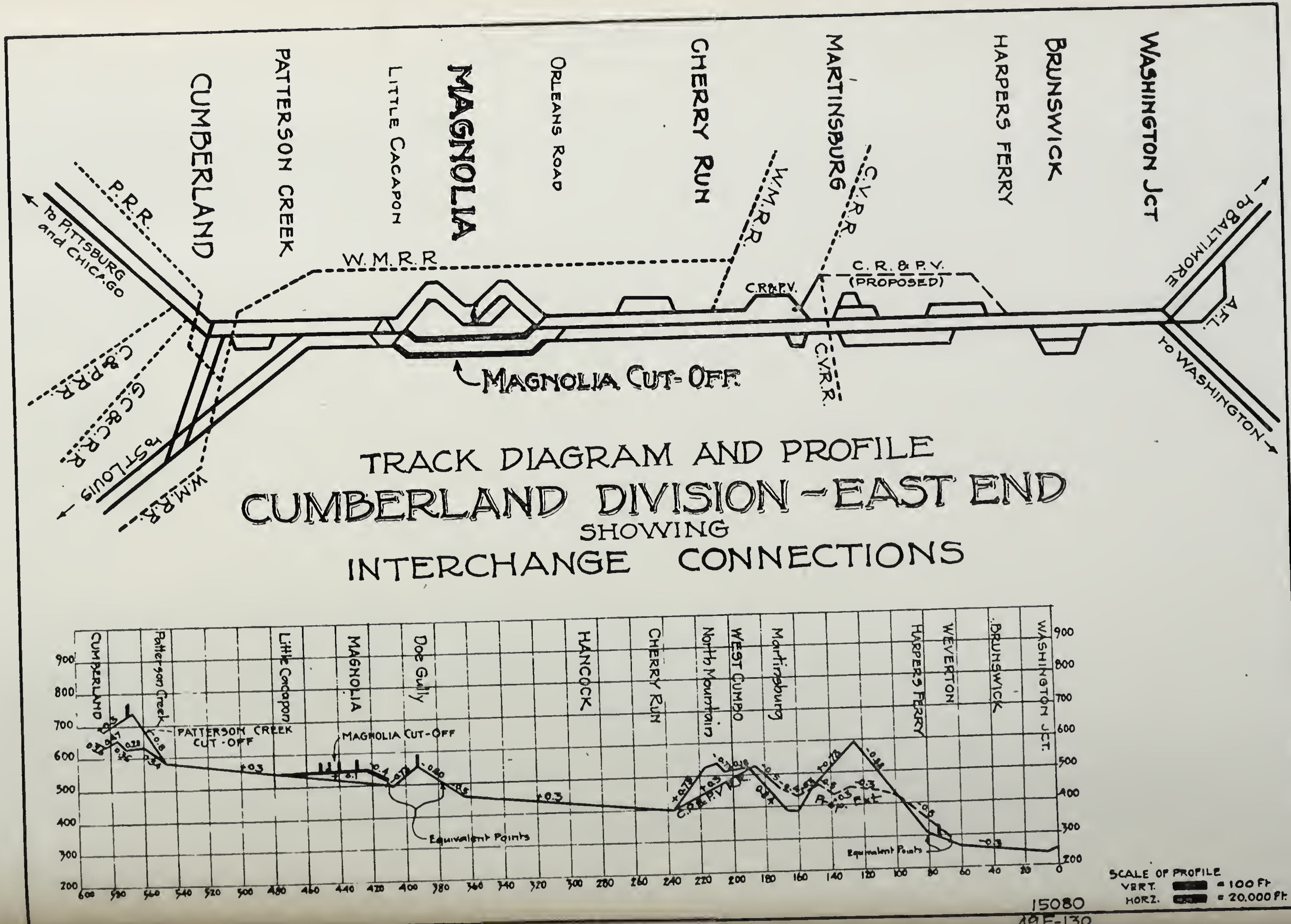


Fig. 34. Track Diagram and Profile of East End Cumberland Division.

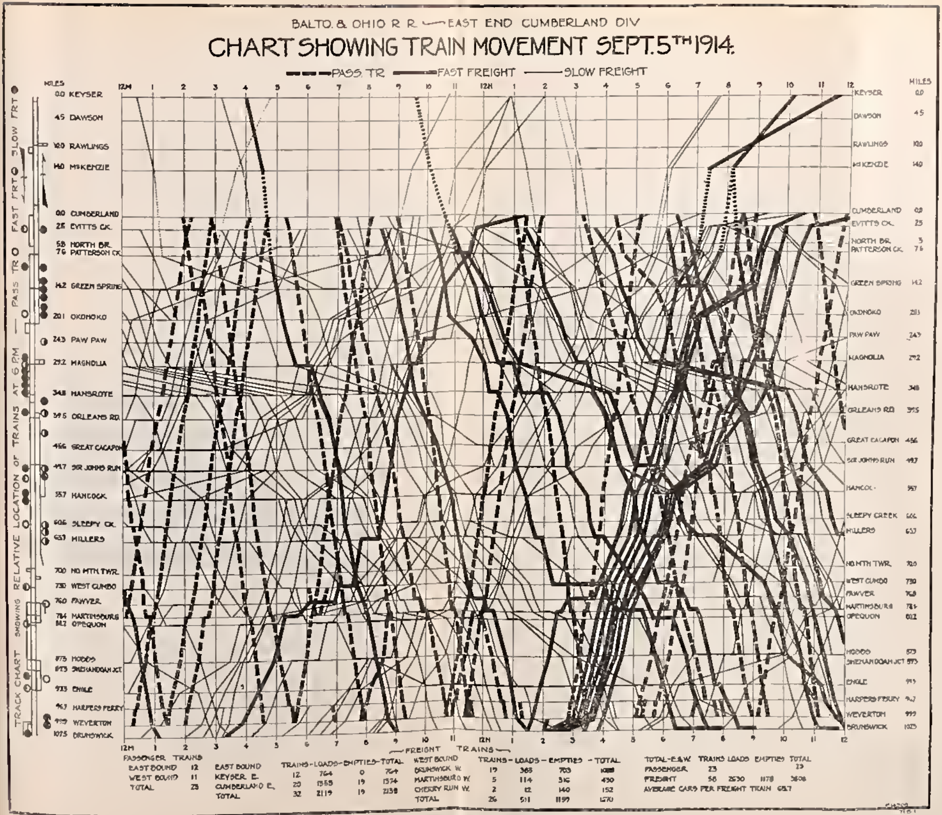
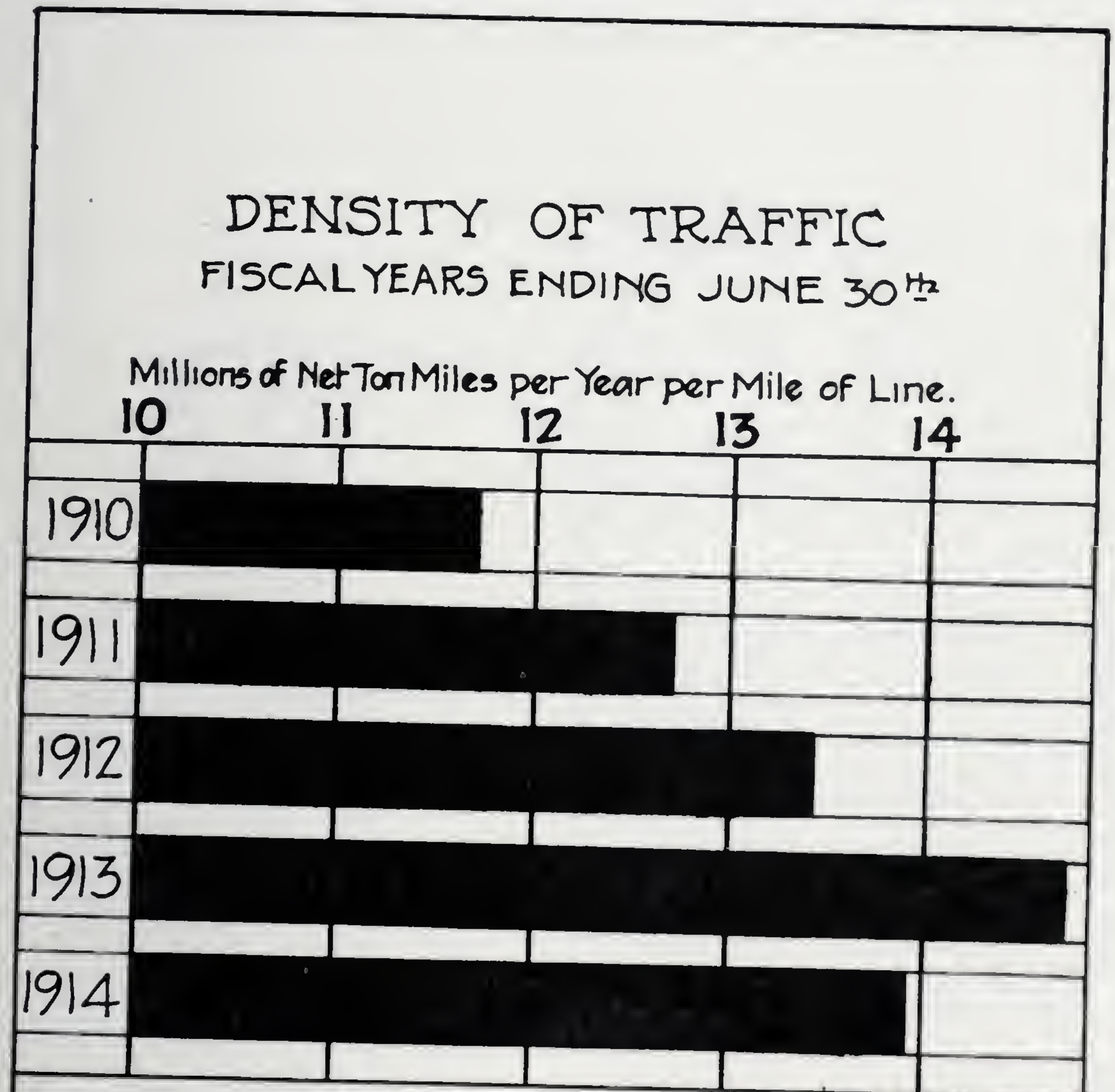


Fig. 25. Twenty-Four Hour Train Movement Chart.
East End Cumberland Division.

From old Fort Frederick to Cumberland, 67 miles, the grades do not exceed 26½ ft. to the mile and the curvatures are generally large, the least radius, and that in but one instance, being 637 ft.

The bridge at Harpers Ferry was built according to the requirements of the United States Government, as the consideration for passing over public property. It was 1700 ft. long and supported on walls and pillars of stone and columns of cast iron. This bridge is still standing and is used for wagon



CUMBERLAND DIVISION - EAST END

Fiscal Years ending June 30th.	Net Ton Miles per Mile of Line	Increase in Net Ton Miles per Mile of Line	Per Cent
1910	11 684 916		
1911	12 693 300	1 008 384	8.6
1912	13 405 181	1 720 265	14.7
1913	14 690 568	3 005 652	25.8
1914	13 910 196	2 225 280	19.1

Fig. 26. Traffic Density Chart.
East End Cumberland Division.

traffic, being one of the old Bollman truss bridges, few of which are still in service.

There were three tunnels on the route to Cumberland: one immediately above Harpers Ferry, 90 ft. long; one at Doe Gully, 1200 ft. long; and the third at Paw Paw Ridge, 250 ft. in length. The Harpers Ferry tunnel was eliminated in 1906 and the Paw Paw tunnel in 1907. Doe Gully tunnel, which will be eliminated early in 1915, marks the elimination of all tunnels on the old line between Harpers Ferry and Cumberland.

The map, Fig. 22, in connection with the various surveys between Baltimore and the Ohio River, is of note. It was

AVERAGE DAILY MOVEMENT—EAST END CUMBERLAND DIVISION

For Period – 10 Days Ended March 10-1914.

	Miles	Pass. Tr.	F.Frt.	S.Frt.	Total	Lds.	Mtys.	Total	Gross Tons per Mile of Road	Tons per Train	Ratio
East											
Keyser to Patterson Creek	20.2	6.4	.3	9.0	9.3	561	3	564	37920	4477	43.1
Cumberland to Patterson Creek	8.1	13.4	5.8	11.6	17.4	929	32	961	48797	2804	55.4
Patterson Creek to Cherry Run	57.1	13.4	6.1	20.7	26.8	1506	38	1544	88048	3285	100.0
Cherry Run to Cumbo	10.8	13.4	6.1	20.6	26.7	1359	31	1390	78590	2943	89.3
Cumbo to Brunswick	26.4	13.4	5.7	12.6	18.3	922	30	952	50387	2761	57.2
West											
Brunswick to Cumbo	26.4	16.2	4.3	13.9	18.2	266	744	1010	24563	1349	60.0
Cumbo to Cherry Run	10.8	16.2	5.3	20.3	25.6	331	1103	1434	35459	1385	86.7
Cherry Run to Patterson Creek	57.1	16.2	5.3	21.7	27.0	387	1237	1624	40907	1515	100.0
Patterson Creek to Cumberland	8.1	16.2	3.5	11.7	15.2	250	537	787	21819	1435	53.3
Patterson Creek to Keyser	20.2	6.2	1.8	9.6	11.4	116	648	763	16980	1489	41.5
Patterson Creek & Cherry R.-E&W			11.4	42.4	53.8	1893	1275	3168	128955	2396	—

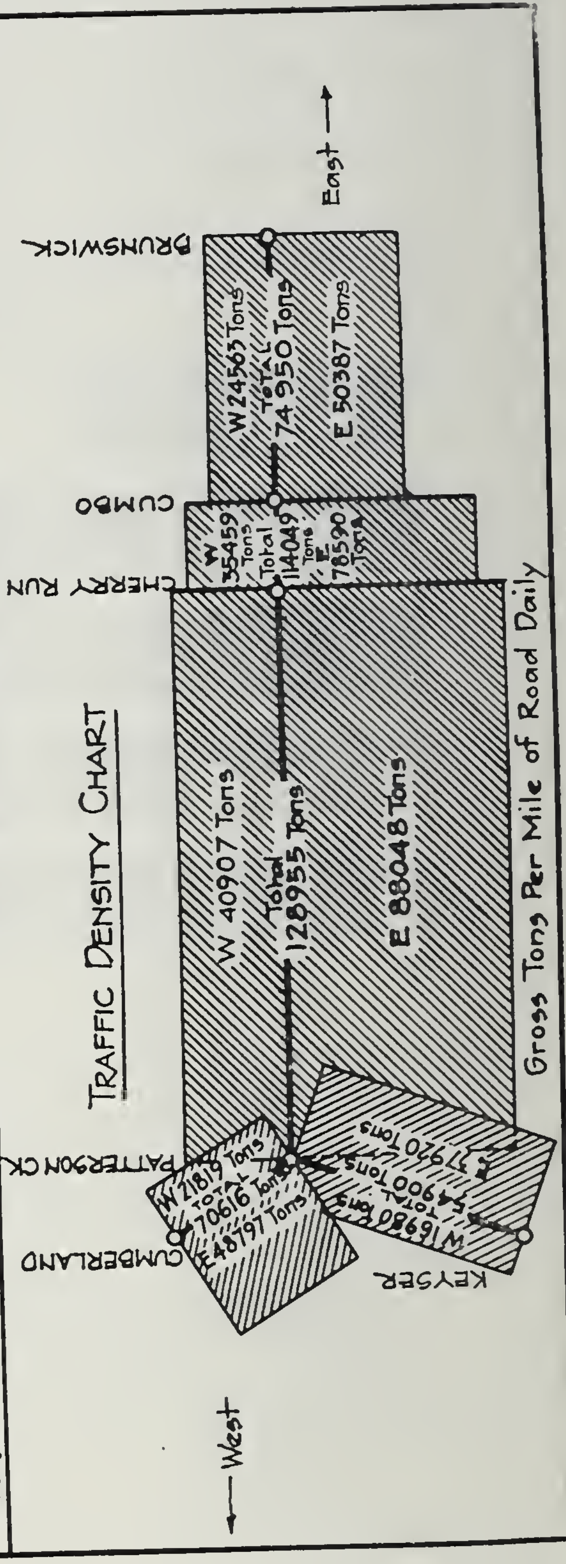


Fig. 27. Average Daily Train Movement. East End Cumberland Division.

drawn from data prepared in 1858, and shows the line of the Baltimore and Ohio as constructed and operated at that time. The heavy broken line shows in general the various routes that were examined and surveyed between Baltimore, Harpers Ferry, Cumberland and Wheeling. At the time data for this map was prepared the line to Pittsburgh was not completed, there being a gap between Cumberland and Connellsville which was finally coupled in 1872.

Table No. 3 was prepared to show the total elevation of ascending grades of the Baltimore and Ohio between tidewater and the Ohio River as compared with other lines.

TABLE NO. 3

COMPARISON OF ASCENDING GRADES

Railroad	Total Ascent	Highest Elevation	From Tidewater	To Ohio River
C. & O.	2372′	2064′ Allegheny	Newport News	Huntington
PENNA.	3513′	2200′ Gallitzin	Philadelphia	Pittsburgh
N. & W.	4934′	2567′ Bluefield	Norfolk	Kenova
B. & O.	4309′	2265′ Sand Patch	Baltimore	Pittsburgh

WHY THE POTOMAC RIVER WAS NOT FOLLOWED

After the Legislature of Virginia in 1838 made it necessary to keep the line on the south side of the Potomac River between Harpers Ferry and a point near Cumberland, the location as adopted and constructed was determined without delay, the following features being carefully considered in this connection:

1. On account of the limited funds of the Company it was desirable to avoid heavy construction work.

2. The line located and constructed through Jefferson and Berkeley Counties, Virginia, touching Martinsburg and passing through North Mountain gap to the Potomac River was shorter than the circuitous route of the river and developed a very flourishing agricultural territory.

3. The line by way of the present Doe Gully tunnel at the expense of a heavy grade cut out the long route that followed the river and eliminated many degrees of curvature.

For reasons which seemed good and sufficient at the time, the Baltimore and Ohio was located and constructed along the

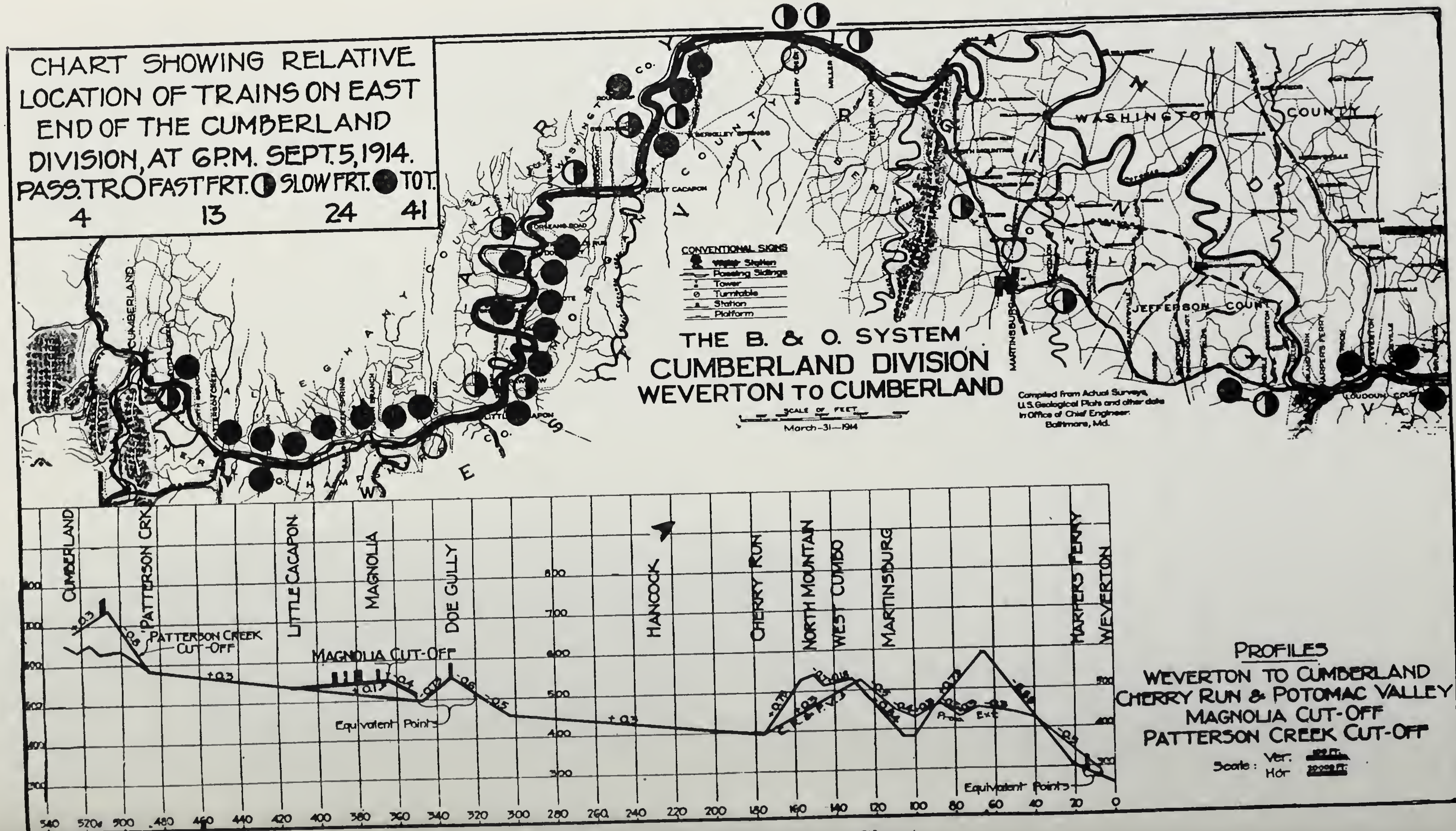


Fig. 28. Train Location Chart.
East End Cumberland Division.

lines as described, but it was not realized how fast the coal tonnage would develop and what difficulties would be brought about by the necessity of more economical operation. If a new project were considered at this time for handling coal from the Maryland, West Virginia and Pennsylvania coal fields to tidewater, undoubtedly a line not exceeding a 0.2 percent grade against eastbound traffic could be built over these ridges to tidewater, which would result in the tidewater terminal being located at some point on the Potomac River.

FALL OF RIVER AND POSSIBLE LOW GRADE LINE

It will be interesting to note, in connection with the location and grades of the line west of Harpers Ferry, Table No. 4 which shows different elevations above tidewater of the Potomac River between Georgetown, D. C. and Cumberland.

TABLE NO. 4

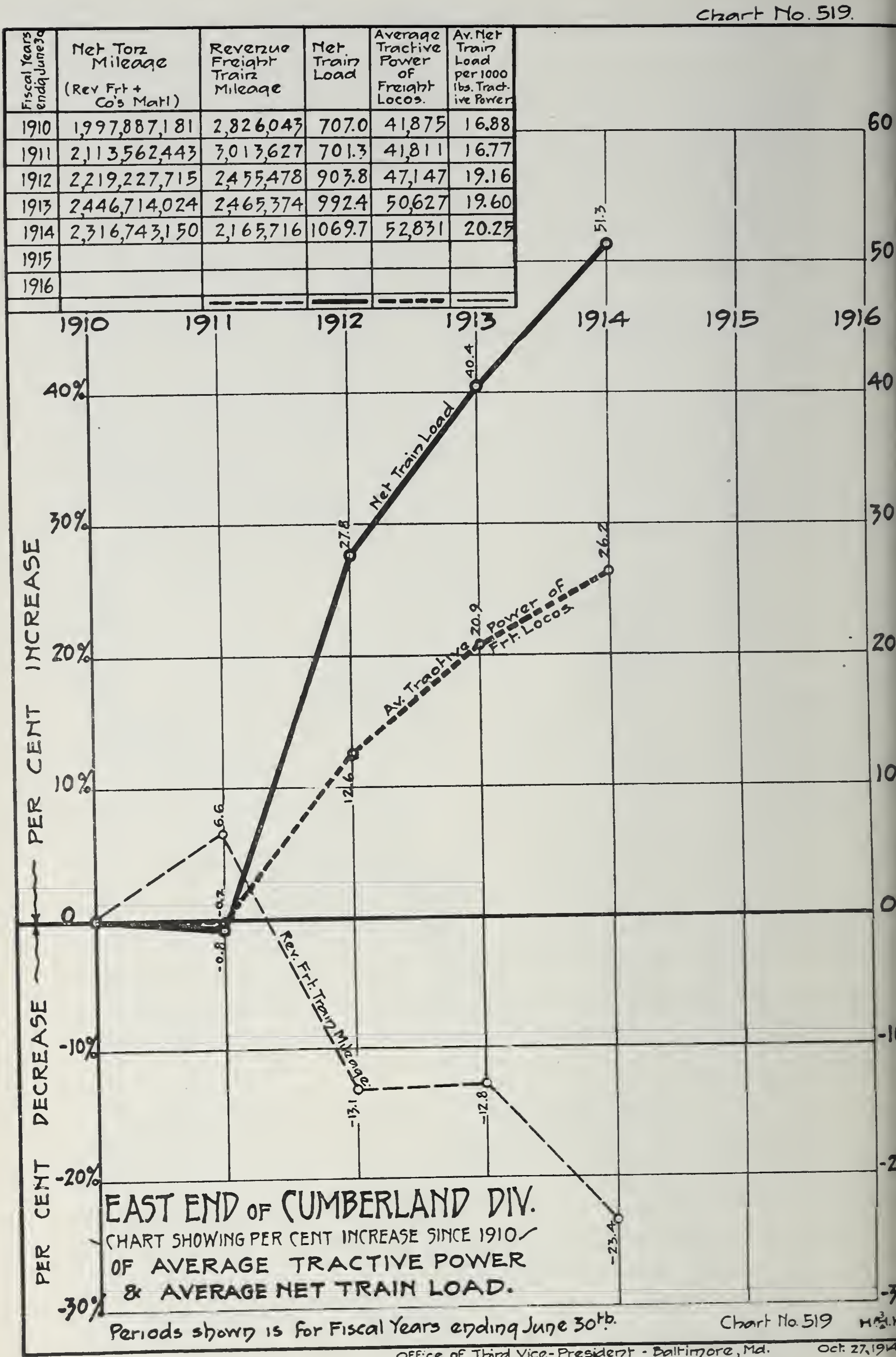
FALL OF POTOMAC RIVER

	Distance from Mouth	Elevation above Tide	Distance between Points	Fall between Points	Fall per Mile
Georgetown	0.0	0	......	.....	.....
Harpers Ferry	61.5	245	61.5	245	4.0
Shepherdstown	71.5	280	10.0	35	3.5
Dam No. 4	85.0	319	13.5	39	2.9
Dam No. 5	107.0	357	22.0	38	1.7
Cumberland	185.0	610	78.0	253	3.2

Had the more winding route of the river been followed the entire distance from Harpers Ferry to Cumberland, a water grade of 0.1 percent, or less, westbound would have been possible. Where the line diverged from the river, shortening distance and eliminating curvature, it was necessary to resort to a grade of about 40 ft. to the mile, or approximately 0.8 percent.

LOW GRADE LINE FROM COAL REGION TO TIDEWATER

In January, 1844, the Board of Directors of the Railroad was officially informed by the President of the Maryland and New York Iron and Coal Company, that having secured the requisite funds for the construction of a railroad from the mines to Cumberland, his company was anxious to proceed with the work if the charges for the transportation of iron and coal from the mines to Baltimore could be fixed at such a rate as would



Fiscal Years end'g June 30	Net Ton Mileage (Rev Frt + Co's Matl)	Revenue Freight Train Mileage	Net Train Load	Average Tractive Power of Freight Locos.	Av. Net Train Load per 1000 lbs. Tractive Power
1910	1,997,887,181	2,826,043	707.0	41,875	16.88
1911	2,113,562,443	3,013,627	701.3	41,811	16.77
1912	2,219,227,715	2,455,478	903.8	47,147	19.16
1913	2,446,714,024	2,465,374	992.4	50,627	19.60
1914	2,316,743,150	2,165,716	1069.7	52,831	20.25
1915					
1916					

Fig. 29. Train Load, Train Mileage and Tractive Power. East End Cumberland Division.

warrant them in adopting the Baltimore and Ohio for the transportation of their products. The same officer also proposed a five-year contract after the completion of the connecting road to furnish the Baltimore and Ohio with as much as 175 tons of coal, pig iron and bar iron, for 300 days in the year. The proposition was finally accepted by the railroad directors and the rate of 1 1-3 cents per ton mile fixed as the freight charge. From this beginning the semi-bituminous coal trade has grown to such proportions that today it requires the Baltimore and Ohio to furnish transportation facilities for hauling 30 000 000 tons a year, the gross revenue from which is 0.4 cents per ton hauled one mile.

During the growth of this great business from the Maryland, West Virginia and Pennsylvania coal fields to tidewater, the question of a more economical operation for this bulk commodity has been constantly studied. Many surveys have been made covering various schemes from the Fairmont region of West Virginia to tidewater. From surveys made during the last 10 years it has been found possible to establish an eastbound low-grade line, beginning at Van Voorhis on the Fairmont, Morgantown and Pittsburgh Branch, and ascending a 0.3 percent grade to the foot of a 20 mile helper grade of 0.75 percent at a point 8 miles west of Pinkerton, on the Connellsville Division. According to preliminary surveys and estimates, it has been found that it would require an expenditure of approximately $17 755 000 to construct a new line and revise the present line on such a basis.

At the summit of the mountain instead of following the present line which has a grade of 1.23 percent through Sand Patch tunnel, another line has been found commencing at Garrett, Pa., having a 0.3 percent eastbound grade, with a tunnel 13 500 ft. in length. This revision would require an expenditure of $4 312 000. The construction of these new lines and revisions would permit a 0.3 percent operation from the Fairmont coal fields eastbound to the summit of the Allegheny mountains, having a helper grade of 20 miles. The grade is descending from the summit of the mountain eastward until the Magnolia Improvement work is reached. At this point the completion of the new improvement will permit of a 0.1 percent east-

Fiscal Year	Freight Trains	Freight Train Mileage	Net Ton Mileage Rev. Frt. & Co's Mat'l.	Loaded Freight Car Mileage	Total Freight Car Mileage	Ave. Tons Per Load'. Frt. Car.
1910	36,082	2826,043	1997887,181	68,539,339	108,438,695	29.2
1911	37,786	3,013,627	2113,562,443	72,467,143	114,972,912	29.2
1912	32,040	2,455,478	2,219,227,715	72,576,485	116,023,877	30.6
1913	31,637	2,465,374	2,446,714,024	75,613,579	120,564,553	32.4
1914	28,527	2,165,716	2,316,743,150	69,990,517	113,743,373	33.1
1915						

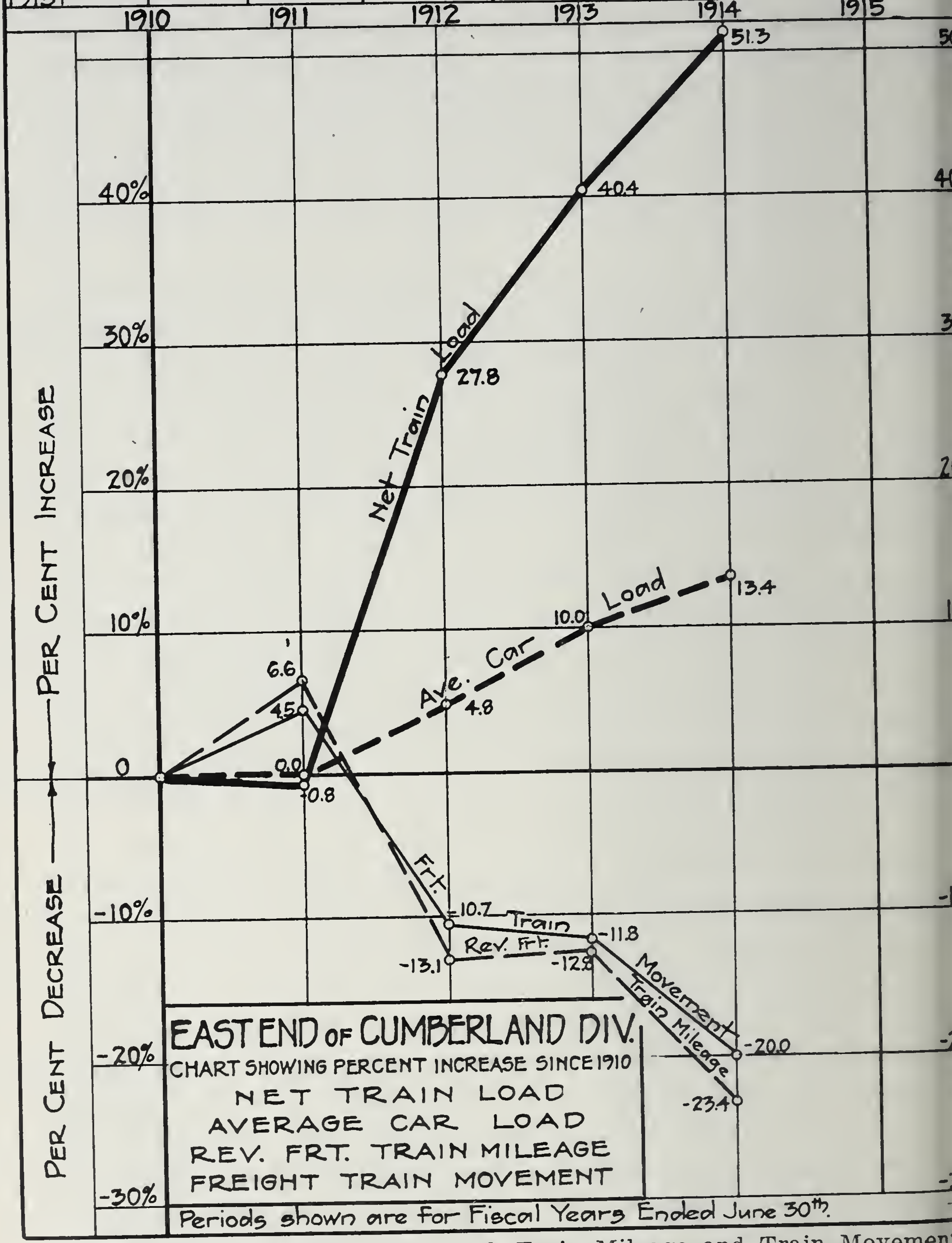


Fig. 30. Car Load, Train Load, Train Mileage and Train Movement East End Cumberland Division.

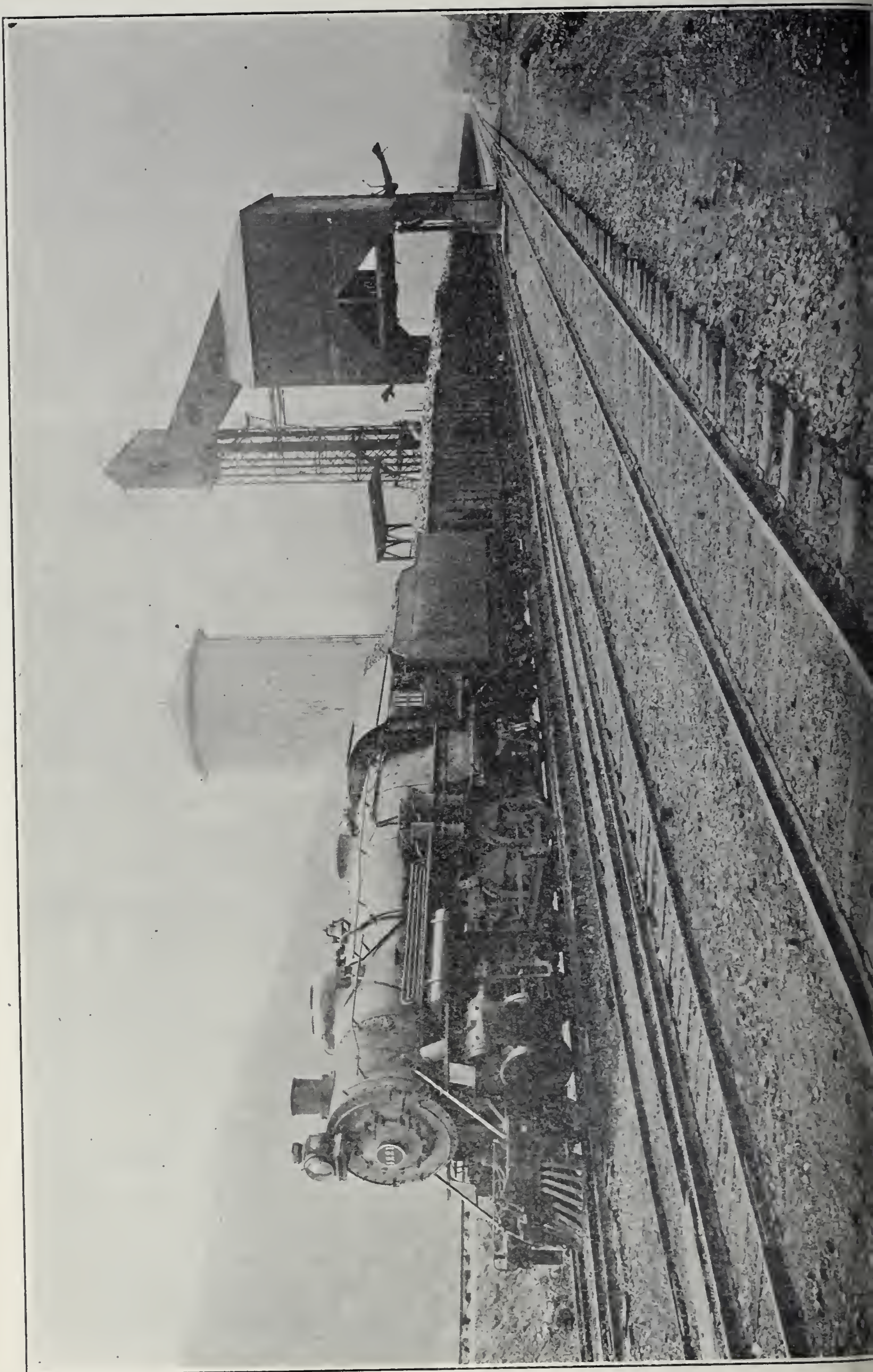
bound operation to Cherry Run where a 0.3 percent helper grade has been established eastward to Hedgesville. From Hedgesville to Harpers Ferry surveys have been completed which show that with an expenditure of $3 500 000 a low grade line can be constructed, having a maximum eastbound grade of 0.1 percent. East from Washington Junction the surveys on the Adamstown Cut-Off show that this line can be revised from a 0.3 percent to a 0.2 percent grade, and on the Old Main Line to the summit of Mt. Airy, 16 miles, the maximum 1.06 percent grade established will permit a 0.2 percent operation, using Mallet helpers.

These surveys covering the various schemes have been made looking toward the future, when it is thought that the great eastbound tonnage will have grown to such proportions that a more economical operation will be necessary and the very large expenditure will be justified in order to obtain this result.

DIFFICULTIES OF EARLY CONSTRUCTION WORK

Having in mind the modern methods of handling construction work, particularly the machinery and explosives used in excavation, the many difficulties which were overcome by the men who first undertook the construction of the Baltimore and Ohio Railroad seem enormous. As ninety percent of the excavation was rock, much of which consisted of the Gabbro and Diabase trap rocks, the hardest rocks known, the difficulties will be appreciated by those who have had actual experience in this character of work. As early as 1830 a cut was made near Baltimore consisting of 310 000 cu. yd. and having a maximum depth of 70 ft. The work was done with hand tools and required 18 months of day and night work, a time nearly as long as it has taken to complete the Magnolia Cut-Off. With the absence of efficient implements the construction of tunnels such as Sand Patch and Kingwood, each being three-quarters of a mile long, must have been very tedious and trying.

Labor conditions perhaps caused as much trouble as lack of equipment. Camps were far away from populated districts and it was difficult to transport men and supplies, all of which resulted in trouble between the contractors and their men. Further difficulty was experienced in securing money with which to pay the workmen and strikes resulted frequently, causing



serious delay to the work; demands for higher wages were made by the men; and high prices were charged by supply houses for materials used on the work.

From the various records it is evident that the importation of liquor to the camps caused demoralization among the men at times and the efforts of some of the contractors to break up the practice resulted in fights and bloodshed.

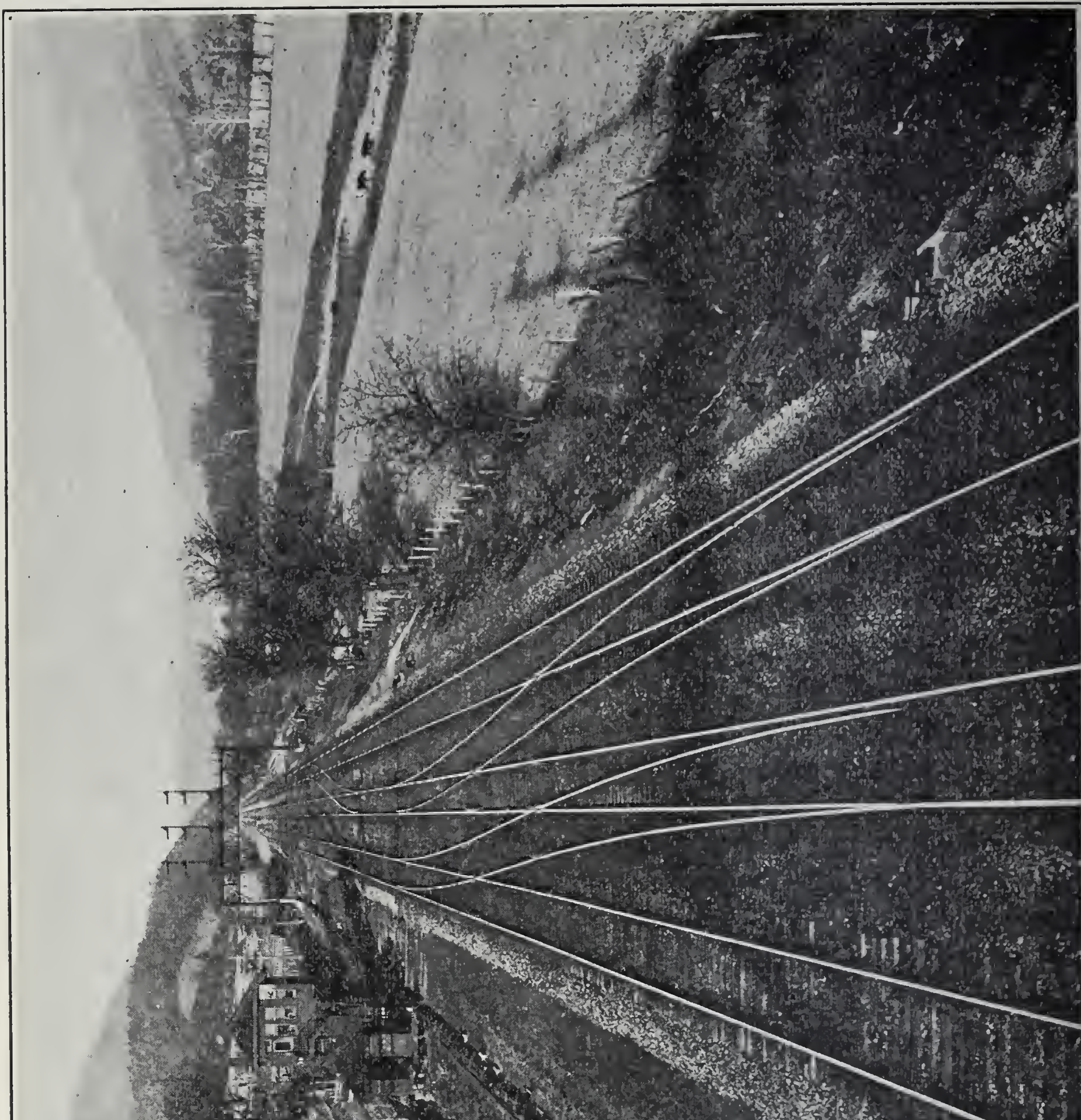
Serious delays were also caused by lack of action on the part of the different legislatures of the states through which the road was constructed, a particular instance being in the state of Virginia, where nearly 10 years elapsed before proper legislation was secured and work started on the line through Point of Rocks and west of Cumberland. In spite of these difficulties, however, a good road was built and much permanent construction in the way of masonry culverts and bridges was secured on this work. An illustrative example is the stone viaduct at Relay, Md., Fig. 23, which was constructed in 1832 and is still in service. This bridge now supports a double track road of standard 13 ft. centers, carrying many times the weight for which it was originally constructed.

A large portion of the yellow pine timber which was used on the line had to be brought from North Carolina by boat to Georgetown, D. C., and from there over the Chesapeake and Ohio Canal and the Baltimore and Ohio to the points where it was used.

Taking into consideration the conditions under which the work was carried on in the early days, the construction of this road is a lasting monument to the energy, foresight and ability of the men under whose direction it was built.

NEED FOR THE MAGNOLIA CUT-OFF IMPROVEMENT

The need for additional facilities east of Cumberland, particularly between Cumberland and Brunswick, has been felt for a number of years. The handling of bituminous coal from the coal fields of Maryland, West Virginia and Pennsylvania to tidewater, together with the comparatively heavy movement of fast freight, have taxed the facilities on this part of the road. On this freight run of 102 miles, see Fig. 24, there were three helper grades, two of which were between Patterson Creek and



Martinsburg, the section of greatest density of traffic. The North Mountain helper grade, six miles in length, was eliminated for slow freight, in 1903, by the construction of a 0.3 percent low grade line around the mountain between Cherry Run and Martinsburg. The first, or Hansrote, helper grade is an 0.8 percent ascending grade against eastbound traffic, and is two and one-half miles in length. It was on account of this helper grade and the very rough country, together with the circuitous route of the river, that this section of the road remained unimproved pending decision in regard to a general change which would eliminate the helper grade, shorten the line and reduce the curvature.

CHARACTER OF FREIGHT TRANSPORTED EAST OF CUMBERLAND

There is a diversified business handled over this line, the preponderance of which is soft coal. Table No. 5 shows the commodities handled by the Baltimore and Ohio in 1913. The East End of the Cumberland Division generally handles about the same proportion of the business as shown in this table.

TABLE NO. 5.
FREIGHT CLASSIFICATION

	Tons	Percent	Earnings	Percent
Merchandise	1 880 904	2.60	7 857 292	9.80
Products of agriculture	4 021 147	5.55	6 796 480	8.47
Products of animals	851 927	1.17	2 790 992	3.48
Products of mines	47 527 410	65.59	37 774 893	47.10
Products of forests	3 063 600	4.23	4 271 657	5.33
Manufactures	12 183 043	16.81	17 540 521	21.87
Fertilizers	417 783	0.58	463 308	0.58
Miscellaneous	2 515 250	3.47	2 699 347	3.37
TOTAL	72 461 064	100.00	$80 194 490	100.00
Passengers carried 1 mile	805 206 527		$15 537 078	
Express revenue			1 909 550	
Mail revenue			1 205 160	

POINTS OF INTERCHANGE AND DIVERGENCE OF TRAFFIC

As shown in Fig. 24, the points of interchange with other railroads are as follows:

Cumberland

Pennsylvania Railroad (Huntingdon & Broad Top Branch).
Cumberland and Pennsylvania Railroad.
Georges Creek and Cumberland Railroad.
Western Maryland Railway.

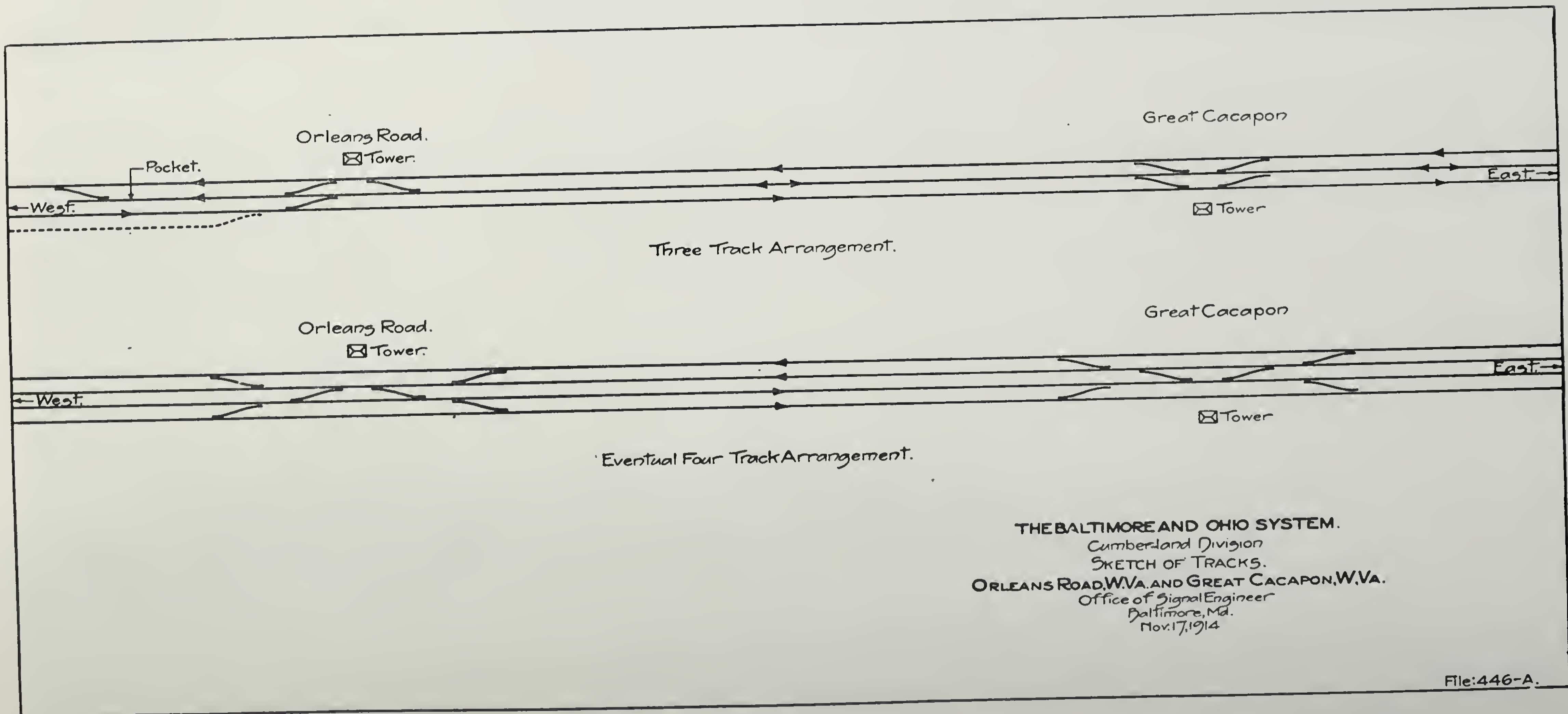


Fig. 33. Present and Ultimate Track Arrangements Extending East from the Magnolia Cut-Off.

Cherry Run

Western Maryland Railway.

Martinsburg

Cumberland Valley Railroad.

At Cherry Run and Martinsburg, 47 and 71 miles, respectively, east of Patterson Creek, there are connections with the Western Maryland and Cumberland Valley Railroads. At these two points 43 percent of the eastbound freight leaves the Baltimore and Ohio for eastern Pennsylvania and New England delivery, coal being the principal commodity diverted. The Cumberland Valley is also the route of the Central States Despatch.

NECESSITY FOR IMPROVEMENT FELT AS EARLY AS 1900

In the coal fields of Maryland, West Virginia and Pennsylvania new developments were constantly being made and additional facilities added to take care of the requirements as rapidly as the business increased; the situation east of Cumberland was gradually growing acute. It had been felt that the rapid growth of the business made possible by the additional facilities west of Cumberland, would result in an over-balance, causing a condition of having more business than could be handled on the line east of Cumberland.

As early as 1900 congestion east of Cumberland was serious at various times and a number of improvements, including the Magnolia Cut-Off, were considered, but owing principally to the heavy expenditure necessary to add to the track facilities along the Potomac River, they were postponed from time to time.

Mr. Willard, now President of the Baltimore and Ohio, who was at that time Assistant General Manager, states that the problem was a serious one and surveys and studies were made for the purpose of determining the best and most practical way to alleviate the situation.

Additional surveys and studies were made at various times to locate the most economical line from the standpoint of operation as well as first cost. In 1902 Mr. L. F. Loree, then President of the Baltimore and Ohio, had exhaustive studies and surveys made for the purpose of solving this problem, as serious congestions occurred on this portion of the road at that time,

but the financial depression of 1903 prevented definite action being taken. Again in 1906 Mr. Oscar G. Murray, who succeeded Mr. Loree as President, had the matter looked into with the result that a line was adopted, but the depression of 1907 prevented anything being done at that time, when it was thought that a new four track railroad, eliminating the old line, costing \$15 000 000 was the solution of the problem.

It remained for Mr. Willard, who returned to the Baltimore and Ohio in 1910, to solve this problem, which was one of the most serious that then confronted the management, and since that time constant thought has been given to working out this difficulty by the most economical and effective methods.

DENSITY OF TRAFFIC ON EAST END OF CUMBERLAND DIVISION

It is difficult to convey to one's mind clearly traffic density. For the purpose of indicating a twenty-four hour movement on the territory under discussion, the train chart, Fig. 25, gives an indication of the density of traffic. At a glance it is readily seen why the territory became known as "The Neck of the Bottle." Four classes of service are handled as follows:

Passenger (including express and mail trains)
Fast freight
Slow freight
Local or way freight

The handling of the passenger and fast freight business promptly through a territory of such density of traffic and limited facilities was a problem not difficult to appreciate. The congestion of slow freight trains at the foot of the helper grade between Magnolia and Hansrote, eastbound, is clearly shown by the black lines, and indicates the amount of time required to cover this short distance of helper grade.

Table No. 6 shows the total daily freight trains, loads, gross tons per mile of road, and ratio which indicates the relative density of traffic very clearly.

TABLE NO. 6
TRAFFIC DENSITY

Between	Frt. Trains	Loads	Gross Tons Per Mile of Road	Ratio
Keyser and Patterson Creek	20.7	677	54 900	42.5
Cumberland and Patterson Creek	32.6	1179	70 616	55.0
Patterson Creek and Cherry Run	53.8	1893	128 955	100.0
Cherry Run and Cumbo	52.3	1690	114 049	88.3
Cumbo and Brunswick	36.5	1188	74 950	58.0

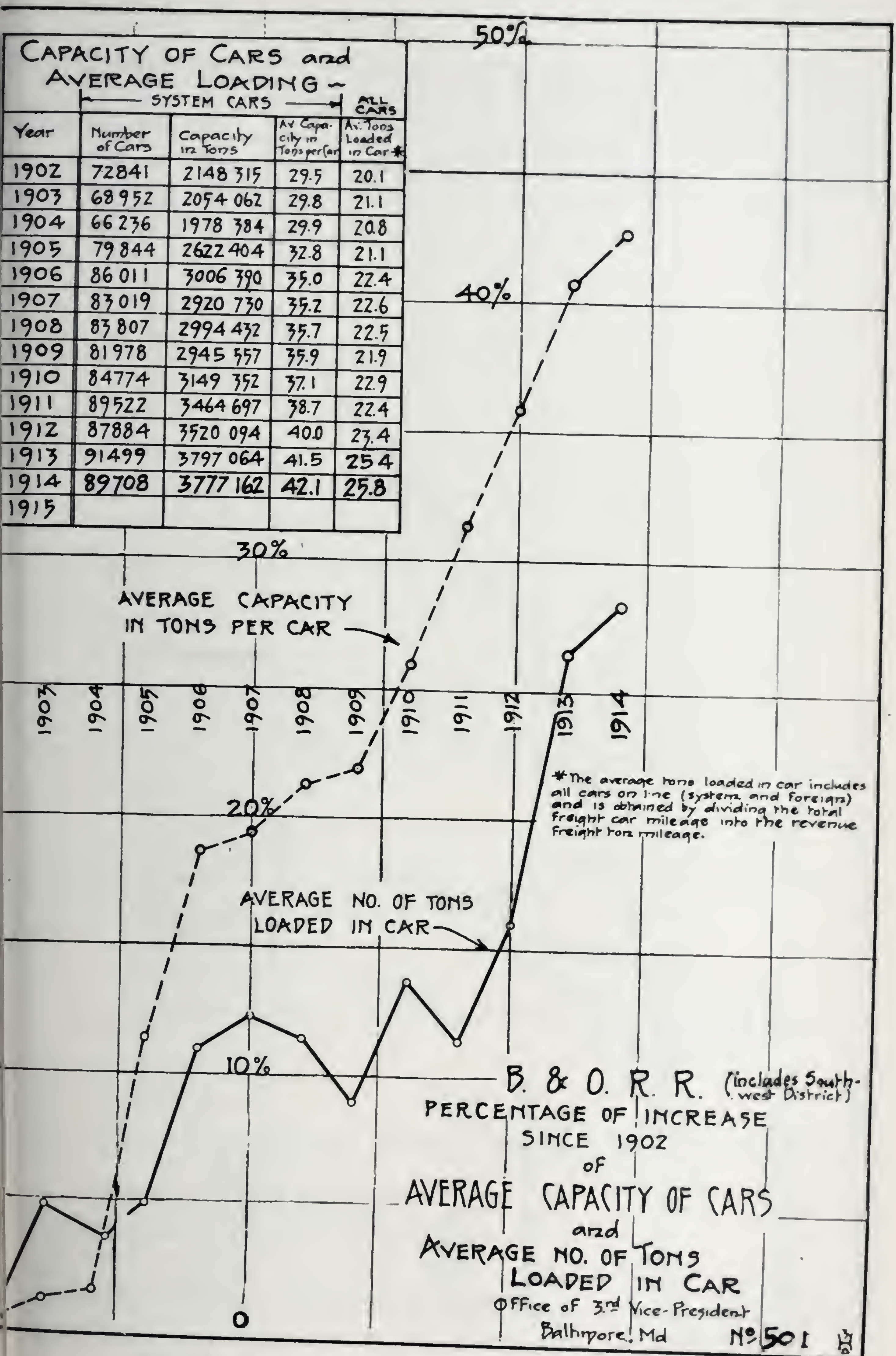
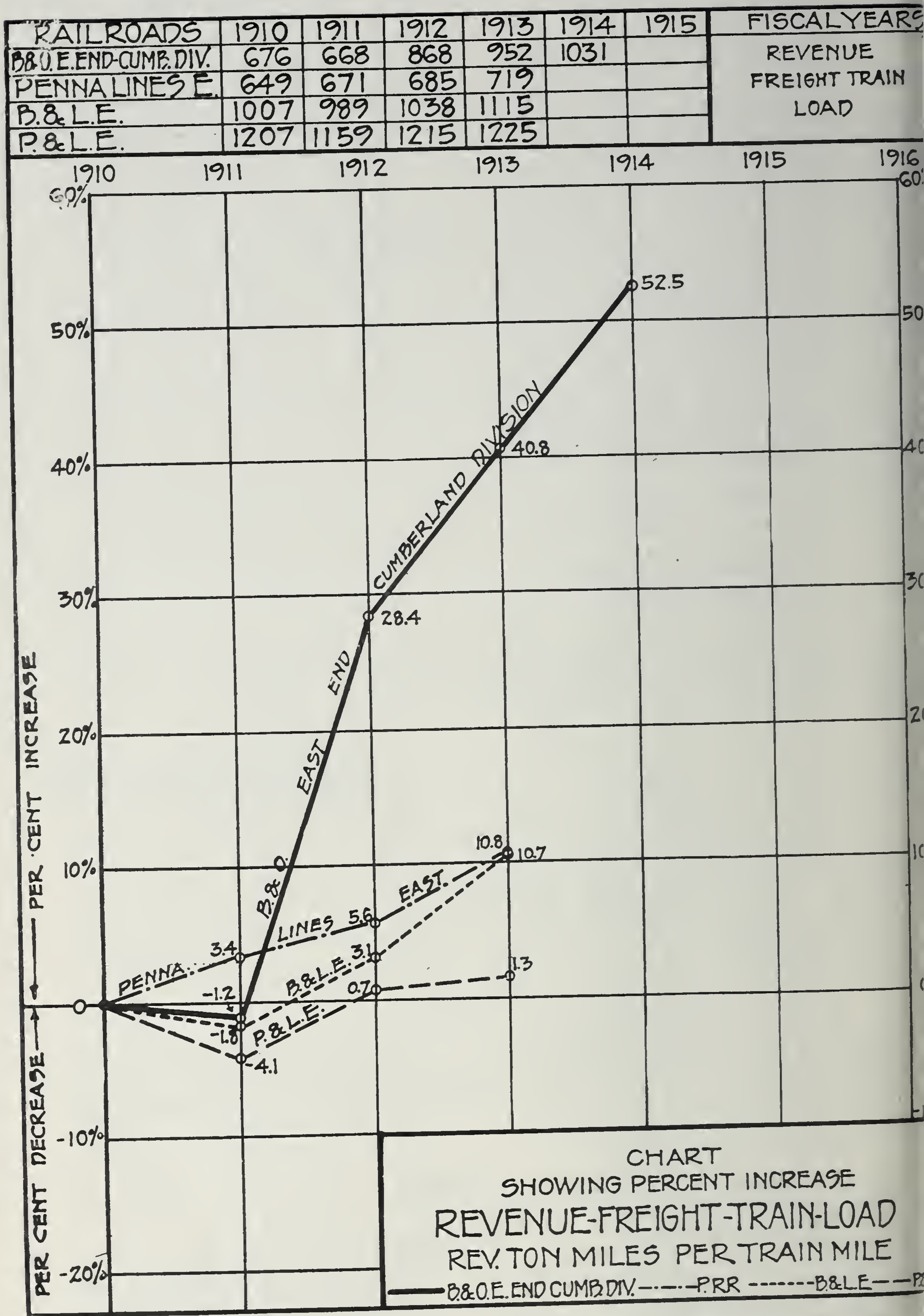


Fig. 34. Average Car Capacity and Average Loading.



RAILROADS	1910	1911	1912	1913	1914	1915	FISCAL YEARS
B&O. E. END-CUMB. DIV.	676	668	868	952	1031		REVENUE FREIGHT TRAIN LOAD
PENNA LINES E.	649	671	685	719			
B.&L.E.	1007	989	1038	1115			
P.&L.E.	1207	1159	1215	1225			

Fig. 35. Increase in Revenue Freight Train Load—Various Railroads.

The greatest density of traffic on the Baltimore and Ohio System, that is, number of trains handled, as well as ton miles per mile of road, obtains east of Cumberland, between Patterson Creek and Martinsburg. There have been handled annually 20 000 000 net tons of freight per mile of road between the above mentioned points, and an average of 15 000 000 net ton miles per mile of road over the entire freight division from Cumberland to Brunswick, the traffic being divided as follows:

14.3 percent fast freight.
84.0 percent slow freight.
2.2 percent package local.

To further illustrate the density of traffic and the rapidly increasing business east of Cumberland, a density chart, Fig. 26, shows the net ton miles per mile of line per year from 1910 to 1914. In 1913, the year of the greatest tonnage handled on the Baltimore and Ohio, there was a 25.8 percent increase over the year 1910.

With such increasing business, the necessity can readily be appreciated for a change in the methods of handling business in this territory in order to take care of additional business, then presenting itself, the congestion on this part of the line being very disturbing.

The density chart, Fig. 27, is interesting in that it shows the daily average movement on the East End of Cumberland Division for a ten-day period. The movement was divided as shown by Table No. 7.

TABLE NO. 7

TRAIN MOVEMENT

		Trains			
	Miles	Pass.	Fast Frt.	Slow Frt.	Total
EAST BOUND:					
Keyser to Patterson Creek	20.2	6.4	.3	9.0	15.7
Cumberland to Patterson Creek	8.1	13.4	5.8	11.6	30.8
Patterson Creek to Cherry Run	57.1	13.4	6.1	20.7	40.2
Cherry Run to Cumbo	10.8	13.4	6.1	20.6	40.1
Cumbo to Brunswick	26.4	13.4	5.7	12.6	31.7
WEST BOUND:					
Brunswick to Cumbo	26.4	16.2	4.3	13.9	34.4
Cumbo to Cherry Run	10.8	16.2	5.3	20.3	41.8
Cherry Run to Patterson Creek	57.1	16.2	5.3	21.7	43.2
Patterson Creek to Cumberland	8.1	16.2	3.5	11.7	31.4
Patterson Creek to Keyser	20.2	6.2	1.8	9.6	17.6

The heaviest tonnage is handled between Patterson Creek and Cherry Run, the number of trains being approximately the same in each direction. The eastbound gross tonnage amounted to 68.1 percent of the total, consisting of 97.5 percent loaded and 2.5 percent empty cars, while the westbound freight movement comprised 23.8 percent loaded and 76.2 percent empty cars. Of the total trains operated 97 percent carried full rated tonnage, which is a very high average. From the density chart it can readily be seen why the operations on that portion of the Cumberland Division between Patterson Creek and Cherry Run are limited by lack of track facilities and why it has been called the "Neck of the Bottle."

The highest average miles per car per day for the Baltimore and Ohio System obtains on the East End of the Cumberland Division for two reasons: First, because of the through movement and the large number of cars handled; and second, because only a small amount of business originates in this territory.

Table No. 8 has been prepared to show the ratio of the daily gross ton miles per mile of road which each section bears to the Patterson Creek and Cherry Run Section. These figures are presented in order to show the relation and necessity of various track facilities comprising the East End of Cumberland Division. It is between Patterson Creek and Cherry Run that the Magnolia Cut-Off Improvement is being made, and it is on this portion of the road, as will be seen from this statement, that the heaviest density of traffic occurs.

TABLE NO. 8

SECTION TONNAGE RATIOS

	Eastbound Ratio	Westbound Ratio	Total Ratio
Keyser and Patterson Creek	43.1	41.5	42.5
Cumberland and Patterson Creek	55.4	53.3	55.0
Patterson Creek and Cherry Run	100.0	100.0	100.0
Cherry Run and Cumbo	89.3	86.7	88.5
Cumbo and Brunswick	57.2	60.0	58.0

As will be seen by the traffic chart, Fig. 25, noted before, the slow movement is on the helper grade between Hansrote and the summit at Doe Gully tunnel, where frequently freight trains on the eastbound main and side tracks wait for track and helper engines. The chart, Fig. 28, shows the relative location

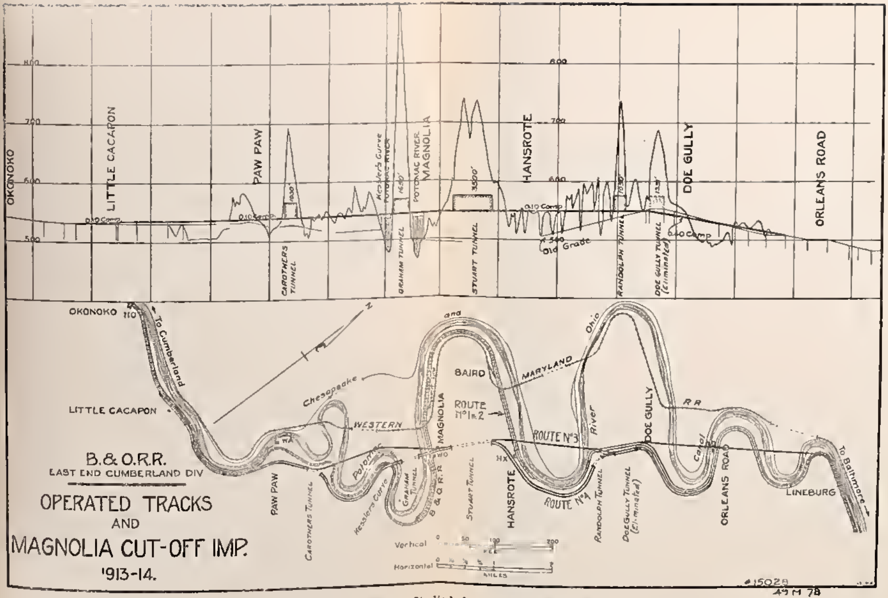


Fig. 36. Various Routes Studied for the Magnolia Cut-Off

of trains at 6:00 P. M., September 5, 1914. As readily noted, the congestion occurred at that time at the foot of the helper grade between Mangolia and Hansrote. Both day and night six or seven eastbound freight trains are in the vicinity of Hansrote helper grade, either moving or waiting for track. On account of the helper engines using the westbound track down the grade the traffic westbound is frequently delayed and the delay of helper engines in turn delays eastbound trains.

TRACK FACILITIES PRIOR TO THE IMPROVEMENT

The East End of the Cumberland Division, a double track road, see Fig. 24, forms one freight division, 102 miles long, and extends from Cumberland to Brunswick. At Cumberland two double track lines, one from Pittsburgh and Chicago, the other from Cincinnati and St. Louis, meet and form the main line east. At Patterson Creek, 8.1 miles east of Cumberland, a freight cut-off joins the main line from the Cincinnati-St. Louis line, which eliminates handling this freight through Cumberland. These two double-track lines merge into a three-track road from Patterson Creek to Little Cacapon, 13.9 miles, at which point there is a westbound passing siding. From the latter point to Magnolia, 7.5 miles, there are but two tracks with a westbound passing siding at Magnolia.

An additional freight running track is provided from Magnolia to Hansrote, 5.5 miles, at the foot of the helper grade. From Hansrote to Orleans Road, 4.7 miles, there are two tracks with an 0.8 percent helper grade eastbound against the ruling movement from Hansrote to the summit at Doe Gully tunnel. From Orleans Road to Cherry Run, 25.3 miles, there are three tracks with a four-track section from Sir Johns Run to Hancock, 5.1 miles.

At Cherry Run the main line, which is double track, ascends an 0.8 percent grade for a distance of 7 miles to the summit at North Mountain. From Cherry Run to Cumbo, there is a low grade eastbound double-track freight line 14 miles in length which passes around North Mountain and joins the main line again at the latter point. From Cumbo to Fawver, three miles, there is a double-track line and from Fawver to Opequon, the foot of a helper grade, there are three tracks, the third being an

eastbound running track. An 0.8 percent ascending grade begins at Opequon, which continues to the summit at Hobbs, 7.3 miles. From this point to Engles, near Harpers Ferry, 5.8 miles, there is a double-track line with an 0.8 percent descending grade, and a westbound third track.

From Engles to Weverton, 6.2 miles, there is a double-track line. Brunswick Yard, the east end of the freight division, is situated immediately east of Weverton.

The division is operated for a general grade of 0.3 percent eastbound, using helper engines over the two 0.8 percent grades.

The low grade around the second summit between Cherry Run and Martinsburg was completed in 1903, eliminating the use of helper engines on a six-mile helper grade between those points. With the completion of the Magnolia Cut-Off, helper engines at Hansrote will be eliminated which will permit of a continuous movement of freight trains between Cumberland and Martinsburg, the part of the road of greatest traffic density, where helper engines have heretofore been necessary. From Martinsburg east over the third summit the service of helper engines will be continued until the low grade line between Martinsburg and Harpers Ferry will have been built.

Ten miles east of Brunswick at the east end of the freight run under discussion, the main line diverges into two double track lines; one to Washington and one to Baltimore. On the line to Baltimore the Adamstown Cut-Off, a low grade line eliminates the necessity for helper engines over one summit.

METHODS ADOPTED TO HANDLE INCREASED BUSINESS

The heavy eastbound traffic over the double-track congested part (referred to as the "Neck of the Bottle") of the East End of Cumberland Division in the latter part of 1910, particularly the tidewater coal business, caused so much anxiety on the part of the President and Operating Officers that conditions east of Cumberland were given particular attention and study with a view of taking care of the business offered at that time as well as to provide for increased business.

Had the revision of grade and line schemes all been worked out and decided upon, and the money appropriated, completion of the work could not have been accomplished in time to take

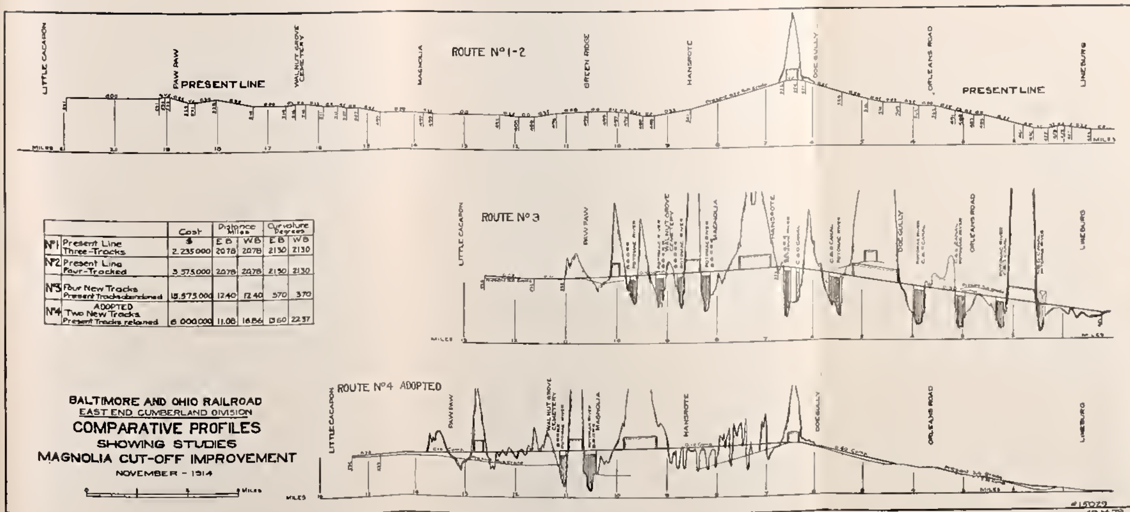


Fig. 37. Profiles of Various Routes Studied for the Magnolia Cut-Off.

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care of the increased business offered. It would have required at least from eighteen months to two years to complete any scheme presented for the Magnolia Cut-Off, and from four to six months to get any relief whatever from third tracks along other portions of the division.

It was necessary to do something at once other than arrange for additional tracks in order to relieve the congestion. Existing financial conditions demanded exceptional care in making expenditures and means were sought to improve operating conditions so as to meet the demands of a rapidly increasing traffic without making the heavy expenditure at this time necessary in the construction of the Magnolia Cut-Off.

In order to secure immediate results, it was decided to:

> Order Mikado locomotives for immediate delivery.
>
> Construct additional automatic signals and build third tracks where they could be laid on that portion of the line not affected by the proposed Magnolia Cut-Off.
>
> Establish signal indication for the operation of trains.
>
> Provide more and better supervision.

At first attention was given to reducing the number of trains to be handled by using first class Consolidation locomotives, establishing their maximum tonnage by dynamometer car tests, thus obtaining the maximum number of net ton miles per train mile. This type of locomotive, called a 100 percent engine on the Baltimore and Ohio, was the heaviest used in 1910 in freight service; it weighed 220 370 lb. and had a tractive power of 42 000 lb. Then a vigorous campaign was started for a better carload, a decrease in the number of cars hauled and an increase in the number of revenue tons per train.

It was an opportune time, as to delivery and price, to purchase locomotives. A Mikado type of locomotive was decided upon, designed and a sufficient number ordered to equip the East End of the Cumberland Division. How well these locomotives, which weigh 284 500 lb. and have 55 000 lb. tractive power with 26.2 percent greater hauling capacity than the Consolidation locomotive, performed is shown by the charts, Figs 29 and 30.

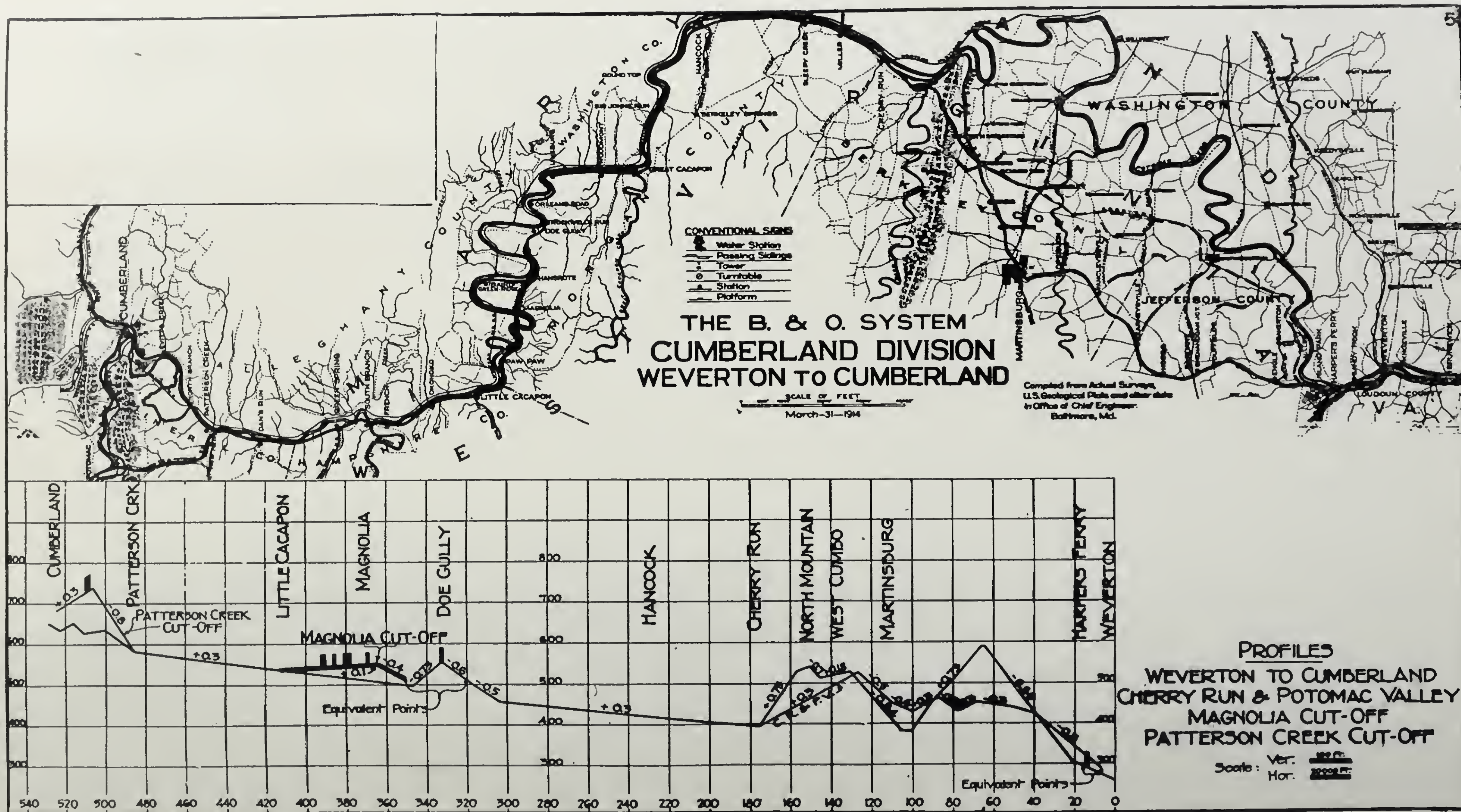


Fig. 38. Existing and Proposed Lines between Weverton and Cumberland.

The following salient features are tabulated from Fig. 29:

	1910	1914	Increase or Decrease
Average tractive power of freight locomotive...	41 875 lb.	52 831 lb.	26.2
Average freight train load	707 tons	1070 tons	51.3
Net train load per 1,000 lb. of tractive power..	16.9 tons	20.3 tons	20.0
Revenue freight train mileage..................	2 826 043	2 165 716	23.4

The charts also indicate that the rate of increase in train load was greater than the rate of increase in average tractive power of freight locomotives. With the track facilities available the increased train load was necessary to handle the traffic. The policy of increasing the train load has had a very beneficial effect on the entire Baltimore and Ohio System.

Fig. 31 shows Mikado engine 4221 with 63 steel hopper cars of coal. Gross weight of cars and contents, 9 173 000 lb., or net weight of contents 6 703 400 lb. Distance covered by the train from Keyser to Brunswick 117.2 miles.

The various passing sidings and freight tracks both east and west of the seventeen mile section of road which was to be improved by the Magnolia Cut-Off, were coupled and extended to this section, thereby securing maximum freight running trackage for a considerable distance at each end of the proposed improvement.

An interesting feature in the development of the three-track scheme is shown by Figs. 32 and 33, and was the result of studies by the Engineering and Signal Departments to get the most out of the three-track layout. Interlocking towers were placed five miles apart and cross-overs constructed between tracks, to permit of parallel movements.

Fig. 32 is a photograph of the cross-over lay-out, looking west at Great Cacapon, W. Va. The interlocking tower is noted on the left and the signal bridge spanning three tracks in the distance. In Fig. 33, the upper diagram indicates the present three-track arrangement between Orleans Road, the east end of the Magnolia Cut-Off Improvement, and Great Cacapon, W. Va.; the lower diagram indicates the eventual four track plan between these two points.

In the three-track layout the middle track was equipped

with automatic signals to permit of movement in both directions. All three tracks were laid on stone ballast and surfaced for high-speed trains. The movement of trains in this district was also placed under signal indication, eliminating train order movements, the third track system particularly lending itself to increased efficiency because of its flexibility in permitting of almost a four-track operation. No. 16 crossing frogs were installed in cross-overs, which when used were covered by upper quadrant slow speed signal blades.

A main track coaling tipple, ash pits and water facilities were placed at Sir Johns Run, half way on the freight run east from Cumberland; this section, five miles long, was arranged on a four-track basis. These improvements and facilities shown by Fig. 31 made it possible to take care of a very heavy business, which was particularly desirable, in fact, necessary, and also produced a reduction in the cost of operation.

Additional supervision was placed on this part of the road and consisted of a force of well-trained men, who were placed both on line of road and in the Superintendent's office. Particular attention was given to following the make-up of trains, to reduce the number of breaks-in-two to a minimum, and further to see that each train was given its full tonnage rating. Inspectors were also placed in the coal regions, to see that each car was loaded to its capacity. The chart, Fig. 30, shows that in four years, from 1910 to 1914, on the East End of the Cumberland Division, the average carload increased 13.4 percent. The increase in average capacity of system cars during the same period was five tons, or 13.5 percent.

REVIEW OF OPERATIONS FOR FISCAL YEARS 1910 TO 1914

A review of the operations in this territory covering the period of the fiscal years 1910 to 1914 inclusive, shows a constantly increasing business with better operating results throughout.

Table No. 9 shows the average tons loaded in car for five years from 1910 to 1914 on the Baltimore and Ohio. This figure is obtained by dividing the total freight car mileage into the revenue freight ton mileage and includes all cars on line both system and foreign.

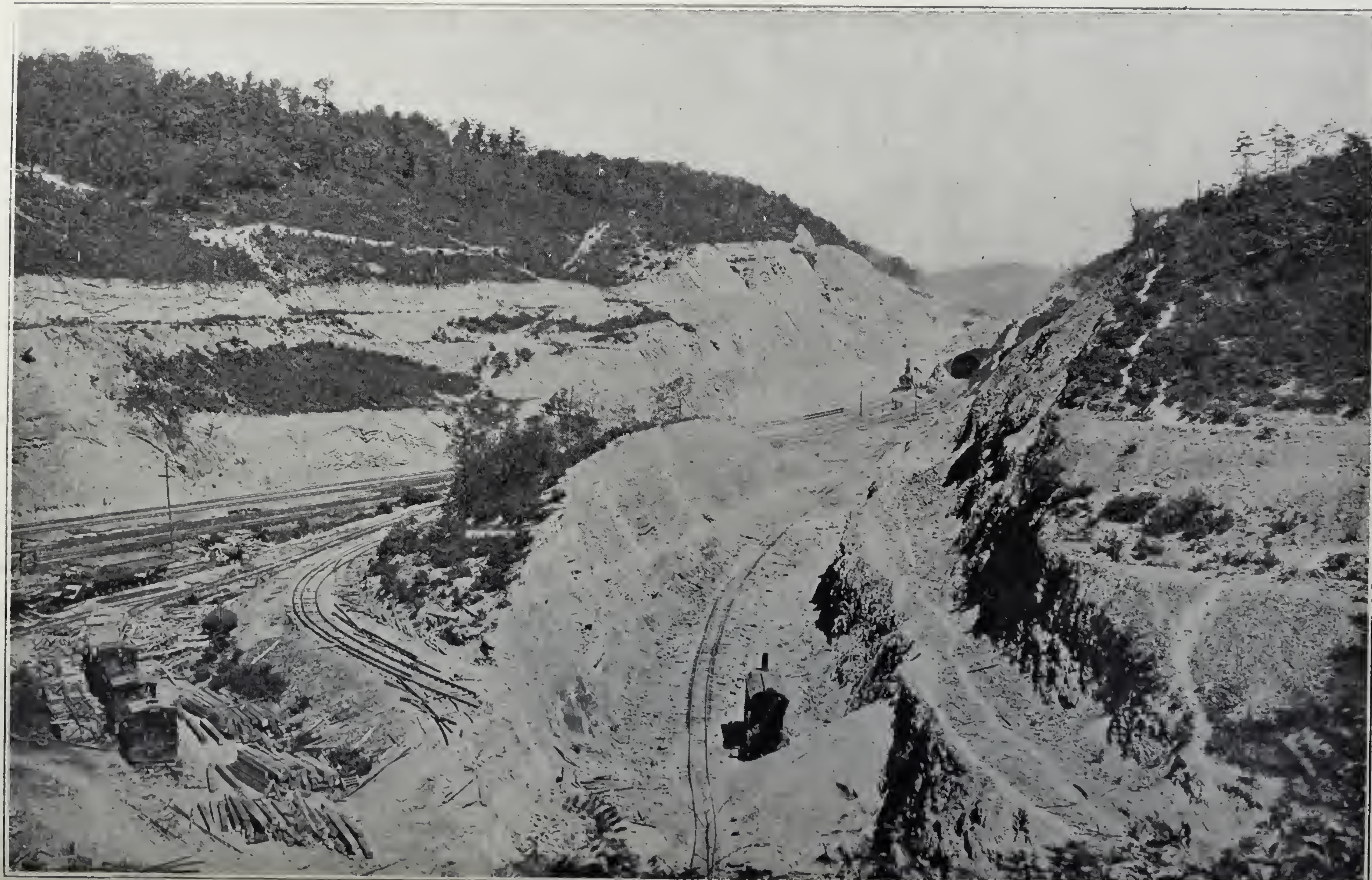


Fig. 40. Doe Gully Cut from East Portal of Randolph Tunnel

TABLE NO. 9

CAPACITY OF CARS AND AVERAGE LOADING

Year	Number of Cars	Capacity in Tons	Average Capacity in Tons per Car	Average Tons Loaded in Car
1910	84 774	3 149 352	37.1	22.9
1911	89 522	3 464 697	38.7	22.4
1912	87 884	3 520 094	40.0	23.4
1913	91 499	3 797 064	41.5	25.4
1914	89 708	3 777 162	42.1	25.8

The graphic chart, Fig. 34, shows that the increase in average capacity in tons per car of system cars from 1902 to 1914 was 42.5 percent. The increase in number of tons loaded in car, based on all cars on line, for the same period was 28.2 percent.

Table No. 10 gives a comparison of operating statistics for the portion of the line between Keyser and Brunswick, based on the fiscal years 1910 and 1914, and shows that a considerably increased volume of business was handled with a marked increase in efficiency.

TABLE NO. 10

OPERATING STATISTICS

Description	Fiscal Years 1910	1914	Increase or Decrease	Per Cent
Miles of Road	117.00	117.00		
Miles of Main Track	344.47	369.73	25.26	7.3
Miles Main Track & Sidings	468.07	504.27	36.20	7.7
Passenger Train Miles	778 198	997 152	218 954	28.1
Passenger Car Miles	6 413 969	7 227 397	813 428	12.7
Avrg. Trac. Power per Pass. Loco	Light Pacific	Heavy Pacific		
Avrg. Mileage per Pass. Loco	15.5	18.9	3.4	21.9
Cars per Train	456 625	760 060	303 435	66.5
Type of Passenger Locomotive	29 500	40 200	10 700	36.3
Avrg. Number of Pass. Locos	4 310	4 475	165	3.8
Tractive Power of Pass. Locos	8.25	7.25	1.00	12.1
Pass. Car Miles per Mile of Road	54 800	61 800	7 000	12.8
Pass. Car Mi. per Mi. Main Track	18 630	19 540	910	4.9
Pass. Car Miles per Locomotive	34 500	31 870	2 630	7.6
Gross Ton Miles	3 976 266 271	4 460 587 008	484 320 737	12.2
Net Ton Miles	1 997 887 181	2 316 743 150	318 855 969	16.0
Rev. Train Miles	2 826 043	2 165 716	660 327	23.4
Freight Engine Miles	3 117 261	2 318 263	798 998	25.6
Loaded Freight Car Miles	68 539 339	69 990 517	1 451 178	2.1
Empty Freight Car Miles	39 899 356	43 752 856	3 853 500	9.7
Total Car Miles	108 438 69[illegible]	113 743 373	5 304 678	4.9
Percent Loaded to Total	63.18	61.53	1.65	2.6
Type of Freight Locomotives	Saturtd Hand-fired Consol.	Superheater Stkr Mikado		
Avrg. No. of Frt. Locomotives	72.9	84.1	11.2	15.4
Trac. Power of Frt. Locomotives	3 054 510	4 448 890	1 394 380	45.6


Randolph Tunnel -

TABLE NO. 10—CONTINUED

Description	Fiscal Years 1910	1914	Increase or Decrease	Per Cent
Avrg. Trac. Power per Frt. Loco....	41 875	52 831	10 956	26.2
Avrg. Mileage per Frt. Locomotive..	42 800	27 600	15 200	35.5
Gross Ton Miles per Mile of Road...	33 970 000	38 130 000	4 160 000	12.2
Gross Ton Mi. per Mi. of Main Track.	11 540 000	12 080 000	540 000	4.7
Gross Ton Miles per Frt. Loco......	54 650 000	53 000 000	1 650 000	3.0
Gross Ton Mi. per 1000 lb. Trac. P'wer.	1 302 000	1 003 000	299 000	23.0
Train Load--Gross	1 408	2 060	652	46.3
Train Load—Net	707	1 070	363	51.3
Eng. Load—Gross	1 276	1 927	651	51.0
Eng. Load—Net	641	1 000	359	56.0
Car Load—Net	29.2	33.1	3.9	13.4

In the four years ended June 30, 1914, the revenue (net) train load increased 51.3 percent with a decrease in the freight train mileage of 23.4 percent. Table No. 11 shows the decrease in number of trains run in that period as being 7555, or 20 percent, with an increase in car mileage of 5 304 680, or 4.9 percent, and an increase in the net ton mileage of 318 855 969, or 16 percent:

TABLE NO. 11

COMPARISONS OF CAR AND TON MILES

Number of freight trains run in 1910	36 082
Number of freight trains run in 1914	28 527
Decrease	7 555
Percent decrease	20.0
Total freight car miles in 1910	108 438 695
Total freight car miles in 1914	113 743 373
Increase	5 304 678
Percent increase	4.9
Net ton miles in 1910	1 997 887 181
Net ton miles in 1914	2 316 743 150
Increase	318 855 969
Percent increase	16.0

It is interesting to note the freight movement in this territory for 1914 compared with 1910, as shown by Table No. 12, which gives the division of traffic from Cumberland, Keyser and Patterson Creek east and Brunswick and Martinsburg west. There was a 30.5 percent decrease in the number of trains run east of Patterson Creek and an increase of 6.9 percent in the business handled. From Brunswick and Martinsburg, the westbound movement shows a decrease of 30.4 percent and 29.4 percent, respectively, in the number of trains run, while the number of cars handled increased 6.3 percent and 14.6 percent.

Fig. 42. Magnolia Bridge and East Portal of Graham Tunnel.

TABLE NO. 12

COMPARISON OF FREIGHT MOVEMENTS

	Trains	% Inc. Dec.	Loads	Empties	Total	% Inc. Dec.
Keyser, East 1910	4749		207207	1470	208677	
Keyser, East 1914	3964	16.5	246414	4638	251052	20.2
Cumberland, East 1910	8795		344744	4194	348938	
Cumberland, East 1914	5450	38.0	333034	12459	345494	1.0
PATTERSON CRK. E...1910	13544		551951	5664	557615	
PATTERSON CRK. E..1914	9414	30.5	579448	17097	596545	6.9
Brunswick, West 1910	9039		118219	233956	352175	
Brunswick, West 1914	6307	30.2	107546	266770	374316	6.3
Martinsburg, West 1910	3412		28160	138095	166255	
Martinsburg, West 1914	2406	29.4	35742	154743	190485	14.6

Table No. 13 and Fig. 30 show by years from 1910 to 1914 the results obtained by better operation on this division as reflected in the number of freight trains, train mileage, train load, total freight car mileage, etc.

TABLE NO. 13

FREIGHT TRAIN STATISTICS

Fiscal Year	Freight Trains	Freight Train Mileage	Net Ton Mi. (Rev. Frt. & Co's Mtl.)	Net Train Load (Tons)
1910	36 082	2 826 043	1 997 887 181	707.0
1911	37 786	3 013 627	2 113 562 443	701.3
1912	32 040	2 455 478	2 219 227 715	903.8
1913	31 637	2 465 374	2 446 714 024	992.4
1914	28 527	2 165 716	2 316 743 150	1069.7

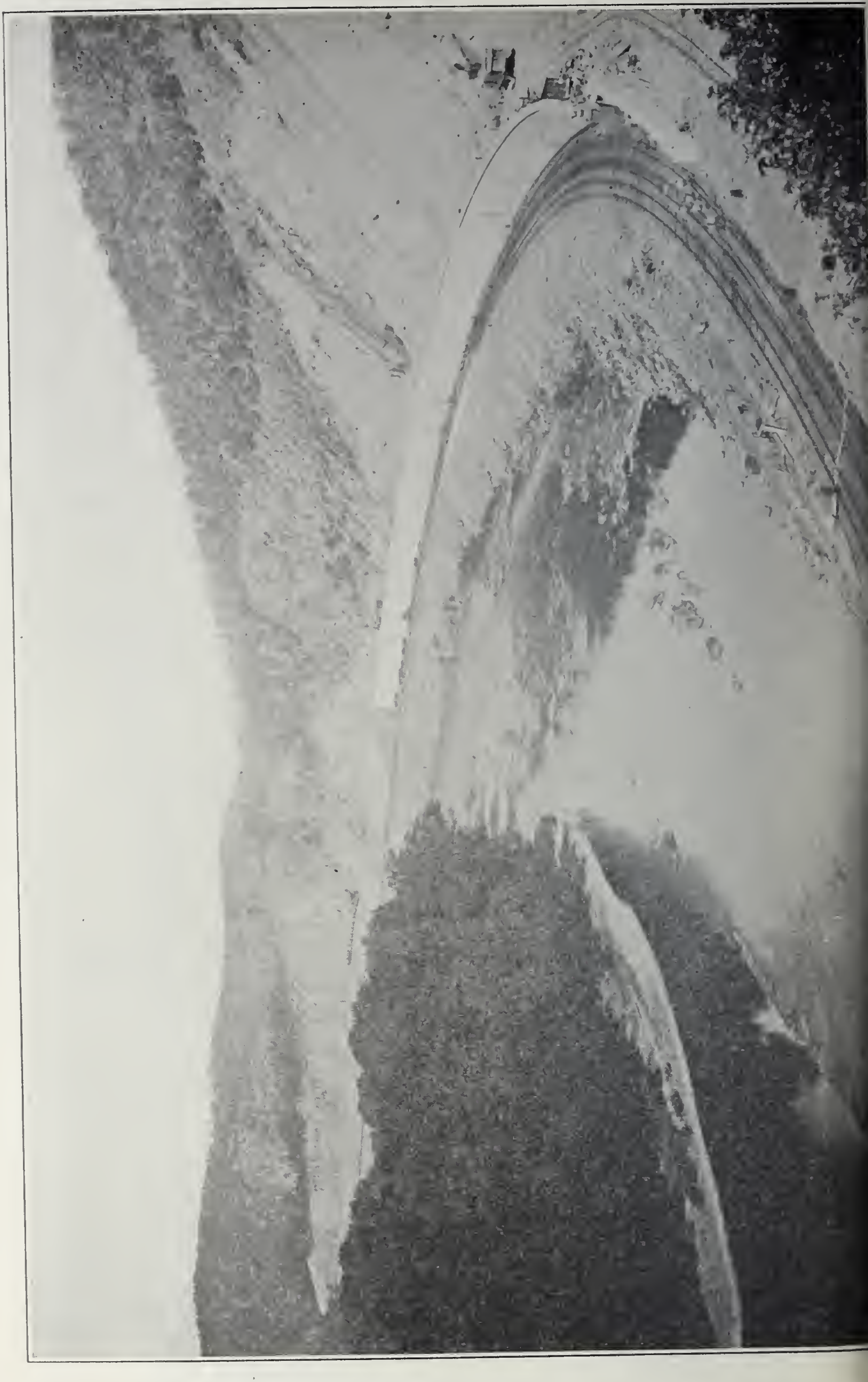
Fiscal Year	Loaded Freight Car Mileage	Total Freight Car Mileage	Average Tons per Loaded Frt. Car
1910	68 539 339	108 438 695	29.2
1911	72 467 143	114 972 912	29.2
1912	72 576 485	116 023 877	30.6
1913	75 613 579	120 564 553	32.4
1914	69 990 517	113 743 373	33.1

To you who are familiar with the Pittsburgh and Lake Erie, Bessemer and Lake Erie and Pennsylvania Lines, Table No. 14 and Fig. 35, showing the train loads of those lines over a period of four years compared with the train load on the east end of the Cumberland Division over the same period, will give an idea of the work done in that direction in the territory under discussion.

TABLE NO. 14

COMPARISON OF AVERAGE TRAIN LOADS

	1910	*1911*	*1912*	*1913*	*1914*
E. E. Cumberland Div. of B. & O...	676	668	868	952	1031
Penna. Lines East	649	671	685	719	—
Bessemer & Lake Erie	1007	989	1038	1115	—
Pgh. & Lake Erie	1207	1159	1215	1225	—



This information is relative only and is presented to indicate what was done on the East End of the Cumberland Division. The opportunities for making this increase were there and the locomotives with heavier tractive power contributed largely to the increased train load. (The Pennsylvania, Bessemer & Lake Erie and the Pittsburgh & Lake Erie are using a Consolidation locomotive with about 20 to 25 percent less tractive power than the Mikado.)

With the improved operations it has been possible to:

1. Take care of a rapidly increasing business.

2. Postpone for three years the construction of the Magnolia improvement, thereby saving the interest on a large sum of money that would otherwise have been expended immediately.

3. Provide additional time for studies of the contemplated line revision.

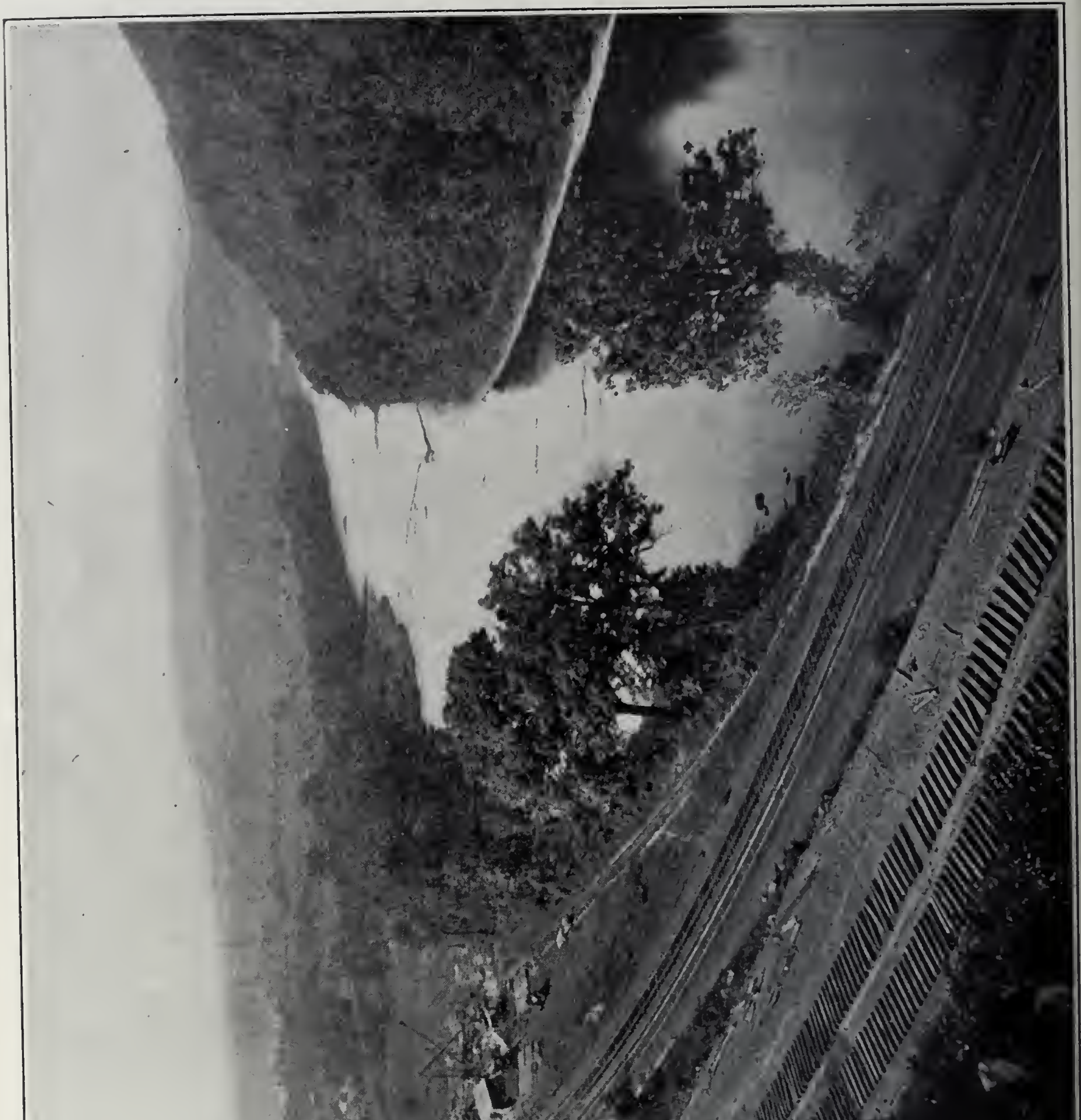
THE MAGNOLIA CUT-OFF IMPROVEMENT

ULTIMATE RULING GRADIENTS

The various studies made toward securing an improved economical operation on the East End of the Cumberland Division have shown that it is possible to obtain grades of 0.1 percent or 0.2 percent against eastbound traffic, which is the loaded and ruling movement, and of 0.15 percent against westbound traffic with 0.4 percent helper grades on certain sections. Over these sections it will be impossible to secure a better westbound gradient than 0.4 percent without unjustified expense. This is particularly true of the westbound 0.4 percent grade from Harpers Ferry to Cumbo Yard at Hedgesville on the route of the proposed line along the river. Therefore, the future maximum westbound movement has been based on a train load which can be hauled on a 0.15 percent grade, using helpers on the sections where there are 0.4 percent grades.

The result of the various studies pointed clearly to the fact that a 0.1 percent grade is justified as compared with either a 0.2 percent grade or the present method of operation.

This grade will permit a maximum eastbound train load, based on the most economical operation and the maintenance



of a proper balance of power between eastbound and westbound movements.

It might be interesting to note here that the minimum ruling gradient, adopted as standard on the Baltimore and Ohio, has been reduced from 0.4 percent in 1901 to 0.3 percent in 1904, to 0.2 percent in 1911, and to 0.1 percent in 1914. When each new standard was adopted it was thought to be the lowest grade consistent with the total number of cars a locomotive was capable of hauling. Due to the development in strength of draft equipment, the number of cars that an engine can haul has been increased, and has resulted in the gradual decrease in the ruling gradient.

The general proposition to obtain better gradients than at present over the entire division will necessitate the building of a low grade line along the river from Cumbo Yard to Harpers Ferry in addition to the completion of the Magnolia Cut-Off. This line has been investigated and the recommendation made, that any future construction of additional tracks between North Mountain and Harpers Ferry should be along this route.

Before the adopted line of the Magnolia Cut-Off was located and construction commenced, the studies included projections on both a 0.1 percent and 0.2 percent basis and, as noted, it will also be possible to obtain either of these grades on the Cumbo-Harpers Ferry river line against eastbound traffic. The present 0.3 percent low grade line from Cherry Run to Cumbo will have to be operated with a light helping engine on either of the propositions of a 0.1 percent or 0.2 percent grade.

After the Cumbo-Harpers Ferry line and Magnolia Cut-Off are constructed there will be very little additional grade reduction necessary to obtain a 0.1 percent grade against the eastbound movement and 0.15 percent grade against the westbound traffic, especially if it is considered necessary to revise on that basis only one track for slow freight in each direction.

Therefore, there seems to be no question that in making all future work on the Cumberland Division conform to the ultimate plan of securing a 0.1 percent operation, which means the hauling of maximum tonnage trains from Keyser and Cumberland to Brunswick, the management is carrying out the

best policy which will result ultimately in a better and more economical operation.

VARIOUS ROUTES CONSIDERED

In taking up the study of the Magnolia Cut-Off Improvement as it relates to the East End of the Cumberland Division, it was necessary to determine the ruling grades both east and westbound on this division. Before this was done a careful study covering a period of several years was made of the train movement and the tonnage handled and the question of motive power was also investigated so as to forecast the future locomotive tractive power and train load. The relation of the loaded eastbound movement to the empty westbound movement was also carefully studied.

It was finally decided that an eastbound grade of 0.1 percent was possible which would permit the most economical operation and that a westbound 0.4 percent grade would take care of the balance of traffic in that direction.

The question as to the construction of a new two or four track line was given a great amount of study and it was found that a low grade four track line would eliminate the present line entirely while a low grade two track line would retain the present line. In this connection four possible propositions were definitely considered involving the construction of:

1. Temporary third track along the present line retaining eastbound helper grade.

2. Additional tracks, providing four tracks along present line and retaining the helper grade.

3. Four track low grade cut-off abandoning present line.

4. Two track eastbound low grade cut-off, using present line for westbound movement.

In reaching a decision between the various grade studies the consideration was constantly in the minds of the engineers, provided it was intended to maintain the present line for westbound movement, that the new line would have to rise sufficiently to cross above the operated tracks at Magnolia and again at Walnut Grove Cemetery.

Before the line was finally adopted a large number of variations of the four different general schemes was studied.

A total of 29 propositions were covered which varied in grade and alignment, following practically the three routes, Nos. 1-2, 3 and 4, as indicated on map—Fig. 36—and profile—Fig. 37. These various studies included plans for building the new line in parts, to be extended over a term of years. The estimated cost of these lines varied from $1 425 000 to $15 575 000.

Table No. 15 shows the estimated cost of constructing a few of the several lines projected; also the annual operating cost, with and without interest, of each line for the present traffic and double that traffic.

TABLE NO. 15

SUMMARY OF COST OF CONSTRUCTION AND OPERATION OF THE DIFFERENT LINES

Line	Cost of New Construction	Number of Trains			
		Present		Double	
		Annual Cost Op.	An. Cost Op. Inc. Int.	Annual Cost Op.	An. Cost Op. Inc. Int.
Present Line and Grade:					
No. 1. 3-Tracks throughout.	$ 2 235 000	$615 087	$ 726 837		
No. 2. 4-Tracks throughout. 0.1% *E.B.* — 0.3% *W.B.*	3 375 000	615 087	783 837	$1 230 174	$1 398 924
No. 3. 4-Tracks throughout. 0.1% *E.B.* — 0.4% *W.B.*	15 575 000	258 724	1 037 474	517 448	1 296 198
No. 4. 2-Tracks throughout*	6 000 000	284 580	584 580	569 160	869 160

*Two new tracks with present line will make four track line.

Table No. 16 shows the saving in distance and curvature for Routes Nos. 1-2, 3 and 4, respectively.

TABLE NO. 16

STATEMENT SHOWING SAVING IN DISTANCE AND CURVATURE

	EASTBOUND				WESTBOUND			
Line	Dist. Miles	Saving Miles	Curvature Degrees	Saving Degrees	Dist. Miles	Saving Miles	Curvature Degrees	Saving Degrees
No. 1	20.8		2130		20.8		2130	
No. 2	20.8		2130		20.8		2130	
No. 3	12.5	8.3	495	1635	12.1	8.7	305	1825
No. 4	15.2	5.6	1380	750	20.8		2130	

The recommended line No. 4 was finally adopted by the President and Board of Directors and construction authorized on March 13, 1913, at an estimated cost of $6 000 000, charging to Additions and Betterments a total of $5 325 000 and to Operation $675 000, upon the basis of the rulings and classifications of the Interstate Commerce Commission.

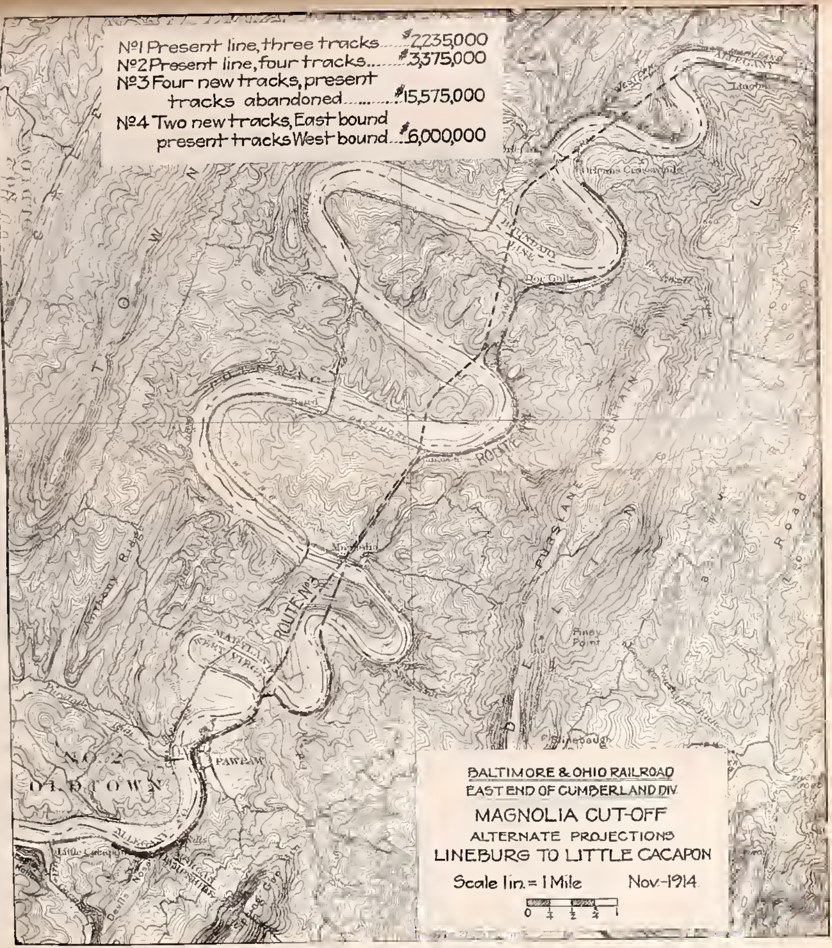


Fig. 46. Topographic Map of Section about the Magnolia Cut-Off.

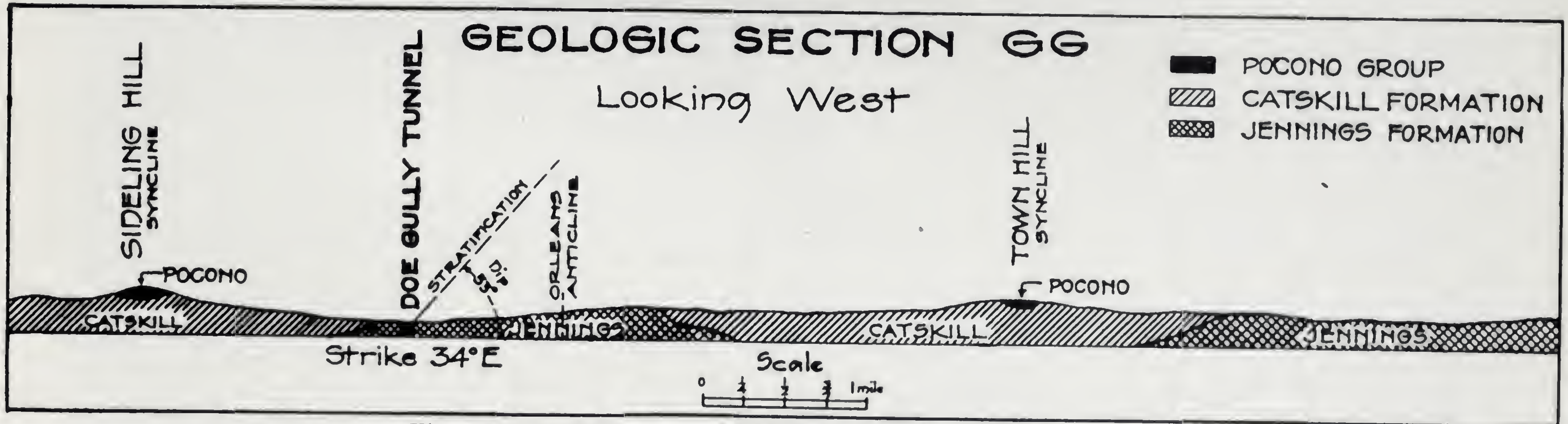


Fig. 47. Geologic Section Through the Magnolia Cut-Off.

LINE ADOPTED

It was concluded that the construction undertaken should follow the plan of a new double track line, using the present operated tracks for westbound traffic. With the line adopted, No. 4, Fig. 36, it has been possible to secure a four track line and derive the benefit from a low grade with the least expenditure. Furthermore, it is believed that the following important characteristics have been secured.

1. A minimum grade, both eastbound and westbound, which will permit the most economical operation.

2. A 0.1 percent grade eastbound possible over the entire East End of the Cumberland Division, which will fit in with a general grade scheme from the coal fields to tidewater.

3. A 0.4 percent grade for westbound business which is practically justified by the probable balance of future traffic.

4. A four track system between Little Cacapon and Orleans Road which will take care of a largely increased volume of business and probably take care of the traffic over the East End of the Cumberland Division for a great many years.

A profile of the Magnolia Cut-Off, together with a profile of the Patterson Creek Cut-Off and the low grade line between Cherry Run and Cumbo and the proposed extension to Harpers Ferry are shown on the map, Fig. 38. The Magnolia Cut-Off provides for the additional tracks and facilities which were absolutely needed in order to handle the present heavy business and provide for a reasonable increase. While certain savings in the cost of operation would result, the line was primarily built to take care of a business that already overtaxed the present facilities.

This section is the first portion of a four-track system which will gradually be extended from Patterson Creek to Brunswick, a distance of 95 miles. It is being constructed on a grade scheme which is in line with a general grade revision of the Baltimore and Ohio from the Maryland, West Virginia and Pennsylvania coal fields to tidewater. This grade scheme is based on the lowest grade that can be secured, the expenditure for which can be justified. In determining the westbound grade on this improvement, studies were made of the operations

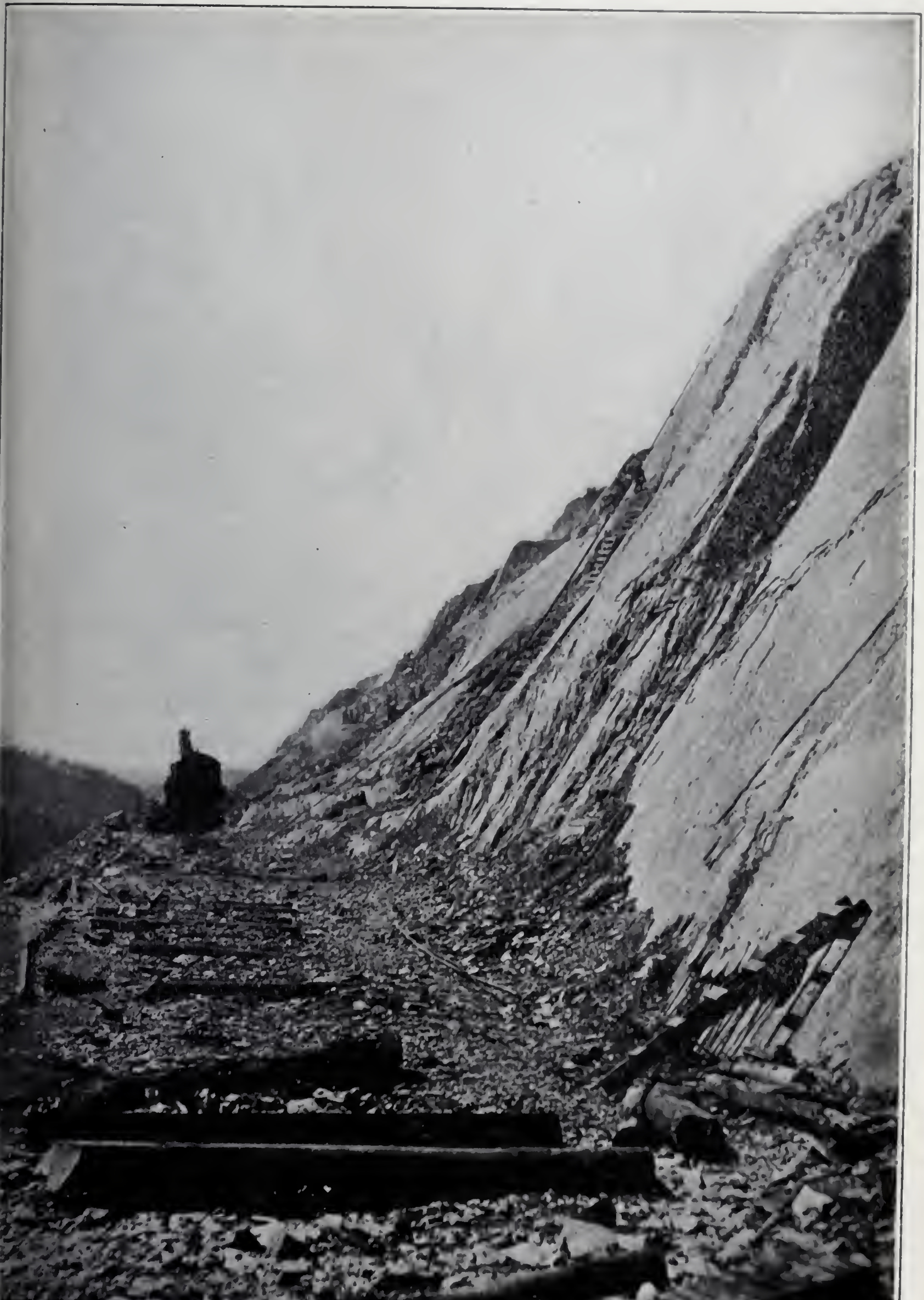


Fig. 48. Bench Showing Slide in Doe Gully Cut.

over the entire part of the Baltimore and Ohio between tidewater and the coal fields, and the probable future balance of traffic was considered. A comparison of the physical characteristics of the present and new line is shown by Table No. 17.

TABLE NO. 17

COMPARISON OF PHYSICAL CHARACTERISTICS OF PRESENT AND NEW LINE

	Present Line	New Line
Grades—eastbound	0.8 U. C.	0.10 C.
westbound	0.55 U. C.	0.40 C.
Distance, miles	16.86	11.08
Curvature	1680 deg.	803 deg.
Maximum curve	9 deg.*	5 deg.
Tunnels . . . . Number	1	4
Length, feet	1331	7100

*Maximum curve to be reduced to 7 deg.
Difference in total length of line—5.78 miles.
Difference in total curvature—877 deg.
U. C. Uncompensated curvature.
C. Compensated Curvature.

SAVING IN OPERATION

The Magnolia Cut-Off Improvement was more essential to the development of the Baltimore and Ohio as a system than for the advantages to be gained from economies in operation. In view, however, of the heavy expenditure necessary to provide the additional tracks for the purpose of eliminating congestion that has heretofore existed in the handling of traffic over the East End of the Cumberland Division, particularly this 17-mile section, it is reasonable to expect a reduction in the operating costs.

Some of the direct savings that may be expected are:

Elimination of Hansrote Helping Station		
Operation of helping engines	$35 000	
Water station facilities	2 000	
Interlocking tower	3 000	$40 000
Overtime account of facilitated movement		20 000
Train mileage, increased tonnage, wages, fuel and supplies, including proportion of locomotives and car repairs		125 000
Less mileage allowance to crews		20 000
Total direct saving per annum		$205 000
Total direct saving per month		17 080

Fig. 49. Bench—7000 ft. East of Doe Gully.

The flexibility in operation brought about by elimination of the cause of congestion will result in a saving equivalent to the cost of operating eight road and two helper engines. It also will avoid bad situations beyond the improved section which will be beneficial in the coal regions where the traffic is assembled as well as at points of destination, especially tidewater, permitting a quicker movement of traffic over the entire system. Conservatively estimated, on the basis of the present business, this saving should amount to approximately $500 000 a year.

METHOD OF OPERATING THE NEW AND OLD LINES

While it has not been definitely decided, it seems from an operating standpoint that the new line can be better operated by using both tracks for eastbound freight trains and the present main tracks and third tracks for east and westbound passenger trains and all westbound freight trains. Although the line is shorter by the new route this advantage, from the standpoint of passenger traffic, is offset by the old line having no tunnels and being along the Potomac River the entire distance. Facilities for handling passenger traffic will, however, be greatly improved by the elimination of the helper station and the removal of the eastbound fast and slow freight trains from the old line.

Table No. 18 shows the estimated cost of adding additional tracks on the present line and grade to make four tracks throughout and the estimated cost of the new two-track line which with the old line will give four tracks. This table also gives the annual operating cost, with and without interest, of each line for the present traffic and double that traffic.

TABLE NO. 18

SUMMARY OF COST OF OPERATION

	Cost of New Construc.	Present Traffic		100 Percent More	
		An. Cost of Op.	Cost of Op. Inc. Int.	An. Cost of Op.	Cost of Op. Inc. Int.
Present Line & Grade 4-tracks	$3 375 000	$615 087	$783 837	$1 230 174	$1 398 924
New Line 2-tracks*	6 000 000	284 580	584 580	569 160	869 160
Saving New Line		330 507	199 257	661 014	529 764

*Two new tracks with present line will make a four track line.

Fig. 50. Hilside Work—West of Orleans Road.

CONSTRUCTION OF THE CUT-OFF

GENERAL DESCRIPTION

The Magnolia Cut-Off Improvement begins at Orleans Road on the east, rising on a 0.4 percent compensated grade to a summit immediately west of Doe Gully, where it begins to descend westward on a 0.1 percent compensated grade to Little Cacapon, a total distance of twelve miles. A saving of 5.78 miles in distance and 877 deg. in curvature is effected. From east to west the main features are as follows:

A double track line diverges from the eastbound side of the present three-track line at a point 1000 ft. west of the interlocking tower at Orleans Road. There a side hill cut is made alongside of the operated tracks, and the line rises on a 0.4 percent compensated grade for 4500 feet to a point where the new line will meet the operated line at grade. The line continues on a 0.4 percent grade through the ridge at Doe Gully, where an open cut is being excavated for four tracks by removing the present Doe Gully Tunnel, the new line continues to a point 500 ft. west of the west portal of the old tunnel where it diverges from the operated tracks on the eastbound side. It then descends with a 0.1 percent grade and instead of following the river around the point, passes through "Randolph Tunnel," which is 1014 ft. in length.

Then continuing with a 0.1 percent descending grade, the line follows the present operated tracks, rising above them on the side of the hill to Hansrote, where it diverges to the south and cuts through the divide by "Stuart Tunnel," 3318 ft. in length. It emerges at Magnolia practically at right angles to the operated line, which it crosses on a continuation of the Potomac River Bridge immediately east of the signal tower. The difference in elevation of the two lines at this point is 50 ft.

Crossing the Potomac River it continues on the 0.1 percent descending grade and passes through the ridge by "Graham Tunnel," 1580 ft. in length, thus cutting off a long loop made by the river around the hill, saving about two miles in distance.

Emerging from "Graham Tunnel" the line again crosses the Potomac River to Kessler's Curve, the bridge crossing the present operated line over head.

Fig. 51. Fill—6000 ft. East of Doe Gully.

Then still descending with a 0.1 percent grade through a small cut, the line follows along the steep hillside on a bench about 40 ft. above, and south of the present tracks. On account of the bluff being almost shear to the operated tracks, a retaining wall 1800 ft. in length is provided between the old and new tracks. West of this inter-track wall the new line again diverges from the old for a short distance and passes through "Carothers Tunnel," 1000 ft. in length. Continuing to descend on a 0.1 percent grade, the line passes the southerly edge of the town of Paw Paw through a cut of considerable proportions.

The four tunnels—Stuart, Carothers, Graham and Randolph—have been named after the present and past Chief Engineers of the Baltimore and Ohio.

At a short distance west of Paw Paw the new line again parallels the present tracks to the east end of the freight pocket at Little Cacapon.

As the present tracks are very close to the Potomac River west of Paw Paw where the river is very narrow, it was found necessary to construct a retaining wall 3100 ft. in length along the riverside to avoid further hillside work. The grade of the new tracks being higher than that of the old, the present line was raised and shifted towards the river and, in conjunction with the new, forms a four-track railroad from the end of the freight pocket to the new inter-locking tower at Little Cacapon.

The quantity of materials handled runs into large proportions when compared with the length of the line. A total of nearly 3 300 000 cu. yd. of unclassified excavation is involved and 6912 lineal ft. of tunnel. The tunnel excavation approximates 240 000 cu. yd. of rock not included in the above figures. The larger proportion of material handled was rock and, due to the irregular and broken formation, offered a difficult problem for solution at several places.

The following general views taken in September, 1914, show clearly the magnitude of this work and give a good impression of the country through which the line passes.

Fig. 39 is a view looking east from the east end of Doe Gully Cut over the four-track fill toward Orleans Road.

Fig. 40 is a view looking east through Doe Gully Cut taken

Fig. 52. Doe Gully Cut, Looking West.

from a point immediately above the east portal of Randolph Tunnel.

Fig. 41 is a view looking east along the hillside toward Randolph Tunnel which can be seen in the distance. Along this part of the line the new grade is about 40 ft. above the present tracks.

Fig. 42 is a view looking down the river toward Magnolia Bridge. The east portal of Graham Tunnel can be seen on the left at the west end of the bridge.

Fig. 43 is a view looking east along the inter-track wall and hillside cut which is located west of Kessler's river crossing.

Fig. 44 is a view looking west toward the east portal cut of Carothers Tunnel.

Fig. 45 is a view looking east along the river wall; the heavy cutting through the town of Paw Paw can be seen in the distance.

GEOLOGY OF COUNTRY

It may be of interest to speak briefly of the geological conditions obtaining in the country through which this improvement is constructed. This new work lies entirely within what is known geologically as the Appalachian Valley, a region of parallel folds of comparatively moderate wave length. The rocks are all sedimentary and belong to the Devonian Age, having a depth of 4000 ft. to 4800 ft. in the Jennings formation.

As noted on the topographic sheet, Fig. 46, the topography is considerably broken up and consists of ridges running in a northeasterly and southwesterly direction, paralleling the Appalachian Range. The Potomac River is the only stream in this locality which cuts across these ridges; it flows through a narrow gorge-like valley and assumes considerable proportions during the period of winter and spring rains.

The tributary streams draining into the Potomac follow the valleys between the ridges and have small creeks running into them substantially at right angles. This "trellis" arrangement of drainage evidently results from the geologic transformation which took place in an early age and was probably caused by the upheaval of the earth's surfuce due to great pressure

in a northeasterly and southwesterly direction which resulted in the formation of ridges at right angles thereto.

The formation represented in the local section, in which lies the Magnolia Improvement, is known as the Jennings, and consists of a buff sandy shale, platy gray shale, soft sandstone and thin conglomerate beds. The stratification of these rocks dips from 53 to 54 deg. east and the strike is about 34 deg. east of north. This condition is indicated on the geological section, Fig. 47, which is taken at right angles to the strike.

From maps, Figs. 36 and 46, it is seen that the general direction of the new work lies parallel to the strike of these rocks, and that because of this condition the easterly slopes of the cuts would expose the ends of the different strata. In general the beds were found to be of widely varying thicknesses and degrees of disintegration. They were fissured and checked very extensively and it was owing to this particular condition that great care had to be exercised in the excavation of the slopes on that part of the new line lying close to the present operated tracks. Careful watch had to be kept at all times to see that none of these blocks of stone, made by the fissures and cracks vertical to the dip, would loosen unexpectedly and fall onto the tracks, and possibly having once loosened they might bring down a considerable area of stone above them.

In dressing the slopes care had to be exercised that no rock was left, a large proportion of which was not thoroughly embedded in the slopes.

Except in the tunnel approaches and in the large cut at Doe Gully, it is generally true that the slopes of the cut lie in the southeast quadrant on sidehill work.

Of course, the best exposure of these rocks was made by the Doe Gully cut, which has a maximum depth of over 200 ft. Here the tunnel tangent lies almost parallel to the strike and on the west side the slope could be made to follow the stratification. Several unexpected conditions were found in this cut due to a decided change or crushing in the plane of the strata. In some cases this caused considerable difficulty in maintaining the slopes and in handling of the work in this unusually large cut. This failure of the strata can be plainly seen in the photograph, Fig. 48, at a point close to the shovel. No indication

Fig. 53. Doe Gully Cut, Looking East.

of these conditions was evident on the approach cuts of the old tunnel or on the surface of the ground. After widening the cut and changing the rate of slope over the area covered by these changes in the beds of the rock, it is thought that no more difficulty will be experienced and that the slopes will be practically self-supporting.

ORLEANS ROAD—SIDEHILL CUT

The hillside work west of Orleans Road presented no great difficulties other than caused by its closeness to the present tracks, as shown by Figs. 49 and 50. The greater percent of the material was rock which was taken out in benches with about 8 ft. cuts. With the exception of such quantities that fell down the slopes and was carried across the tracks below, the material was wasted at the bench levels in the ravines of Rockwells Run and other streams.

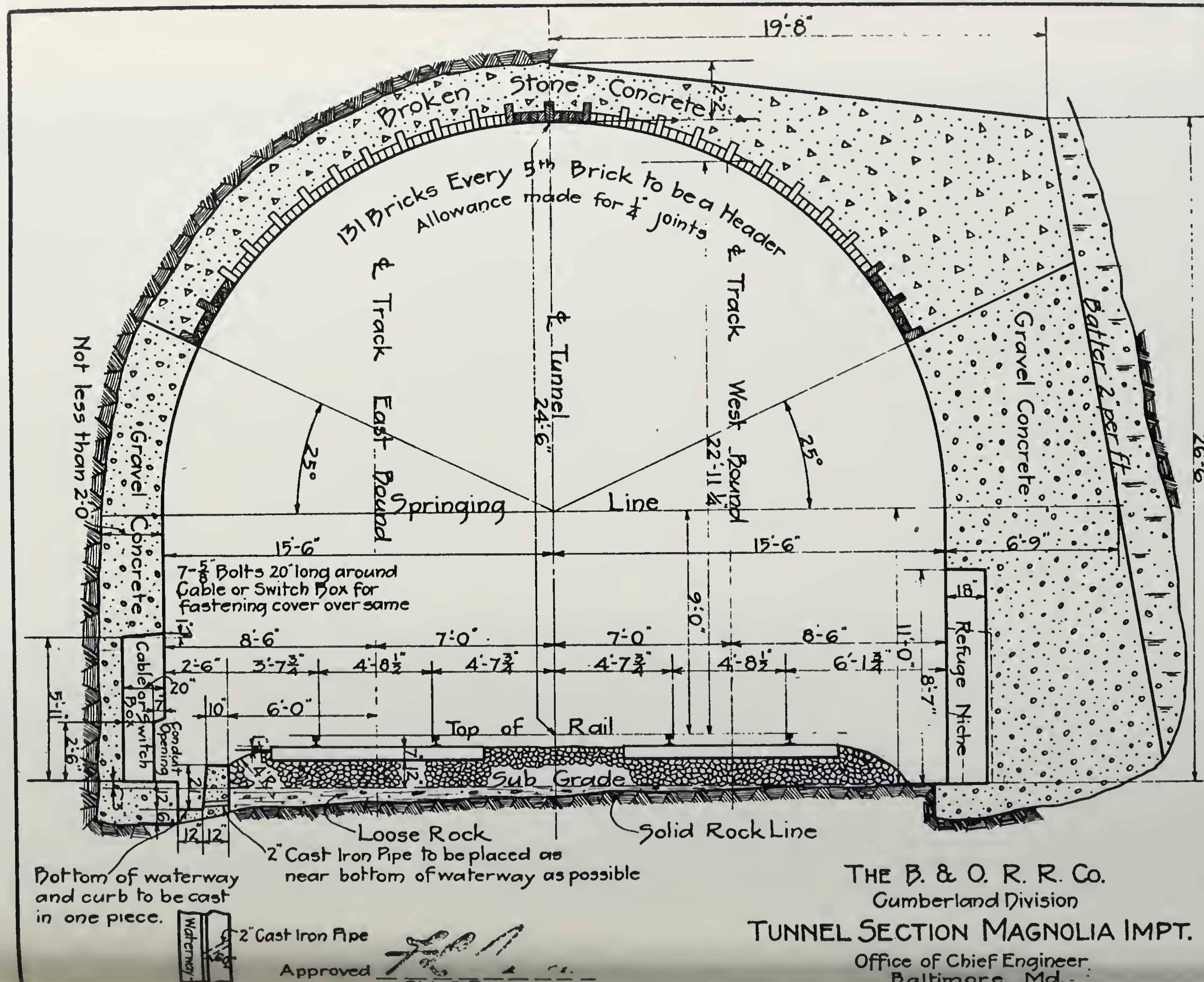
Steam drills were used on this work together with one No. 40 and one No. 60 Marion steam shovel. On account of the nearness to the present tracks, it was necessary to use great care in blasting. A number of men were stationed at the foot of the slope in order to keep the operated tracks clear of loose stones which fell from the work above and to prevent the line from being blocked.

This work was handled by force account labor, as was done on other sections of the improvement.

DOE GULLY EMBANKMENT

At a point about 6000 ft. east of Doe Gully the new line was constructed with a 0.4 percent ascending westbound grade on a large embankment containing approximately 1 000 000 cu. yd. of material. This was possible on account of the large amount of excavation taken from the Doe Gully Cut which would have been entirely wasted had not this provision been made. At the present time two new tracks have been laid on this fill and eventually it is the intention to complete with four tracks and abandon the present two tracks along the hillside.

While this new embankment does not reduce the curvature, it permits a curve of larger radius, having a 4 deg. curve instead of the 6 deg. curve now on the present line. The construction of this embankment was carried out in the usual way,



THE B. & O. R. R. Co.
Cumberland Division
TUNNEL SECTION MAGNOLIA IMPT.
Office of Chief Engineer.
Baltimore. Md.

the material being dumped from temporary trestles, as indicated by Fig. 51.

DOE GULLY CUT

At Doe Gully the double track tunnel is being replaced by a four-track open cut with a maximum depth on center line of 200 ft. and requiring the removal of approximately 1 400 000 cu. yd. of material.

The strata in Doe Gully Cut from surface indications before the work was started appeared to dip in an easterly direction at an angle of about 40 deg. It was planned to take out the west slope in three benches, the faces to coincide with the dip and the easterly face to be sloped one-half to one with two 25 ft. benches.

The grade of the new line is about 12 ft. below the present tracks and on account of the necessity to keep the present double-track tunnel open for continuous service the material in the cut was excavated by steam shovels in the usual manner to within a short distance from the top of the tunnel; then the west side was excavated to grade, leaving a substantial shoulder over the tunnel. A small steam shovel is now at work removing the remainder of the material above the tunnel, after which the tunnel will be removed and excavation carried to grade, completing the cut for four tracks.

After good progress had been made the work was complicated by finding that the strata did not maintain the uniform dip indicated from surface conditions. Instead, they turned and twisted in a most irregular way, being almost vertical in places, bent in others and presenting cracks, as a result of which part of the bench was lost. Over the old tunnel a seam of rotten rock was found and the work which before was cautiously handled was approached with redoubled care. To prevent a tie-up in case of accident to the old tunnel, the new grade was excavated alongside on a gentle slope from each end so that tracks could be laid and traffic taken care of with little delay. Tracks were laid on the new grade and traffic diverted until August when cracks developed and a large slide occurred, which made it necessary to take out the tracks and again put the traffic through the tunnel.

Fig. 55. Bench—1400 ft. West of Randolph Tunnel, Looking East.

One No. 40 Marion, three No. 60 Marion and one No. 73 Bucyrus steam shovels were operated in this cut.

The drilling was all done by air drills, using air at a pressure of 80 lb. for which a six-inch main was laid over the mountain and along the east side of the cut.

On account of the depth of the cut and loose character of the material, the slopes were benched at intervals of fifty feet vertically with gradients of 3 percent upper, 2 percent middle and 1½ percent lower levels. These benches were designed to afford drainage and prevent slides.

Fig. 52 is a view taken in July, 1914, looking west through Doe Gully Cut. It will be noted that the grade has been maintained through the entire cut so that temporary track can be laid in case it becomes necessary to divert traffic from the tunnel. The small steam shovel on the top of the tunnel was used to excavate the remaining material covering the tunnel.

Fig. 53 is a view taken July, 1914, looking east through Doe Gully Cut. It will be noted that about the middle of the view the bench was lost by a small slide.

RANDOLPH TUNNEL

A short distance west of Doe Gully the new line instead of going around the point cuts through the ridge by Randolph Tunnel which is 1014 ft. in length, and on a 4 deg. curve.

The same method of driving was used on all four tunnels, namely: a top heading about 9 ft. by 16 ft. was driven, followed by a No. 60 Marion shovel operated by compressed air which widened it to the full arch section. As the excavation progressed the rock was lined with timber, which was replaced with permanent concrete lining as soon as the shovel work was completed. The standard arch section, as shown by Fig. 54, consists of gravel concrete up to the 25 deg. line, above which point broken stone concrete is used, faced with one course of brick. The tunnel work on the improvement differed from the standard section, as broken stone concrete was used throughout. Every fifth brick is made a header to secure a bond with the concrete. It was found during the past several years that concrete lining in the tunnels was seriously affected by the gases from locomotives, causing rapid deterioration of the concrete. Experience

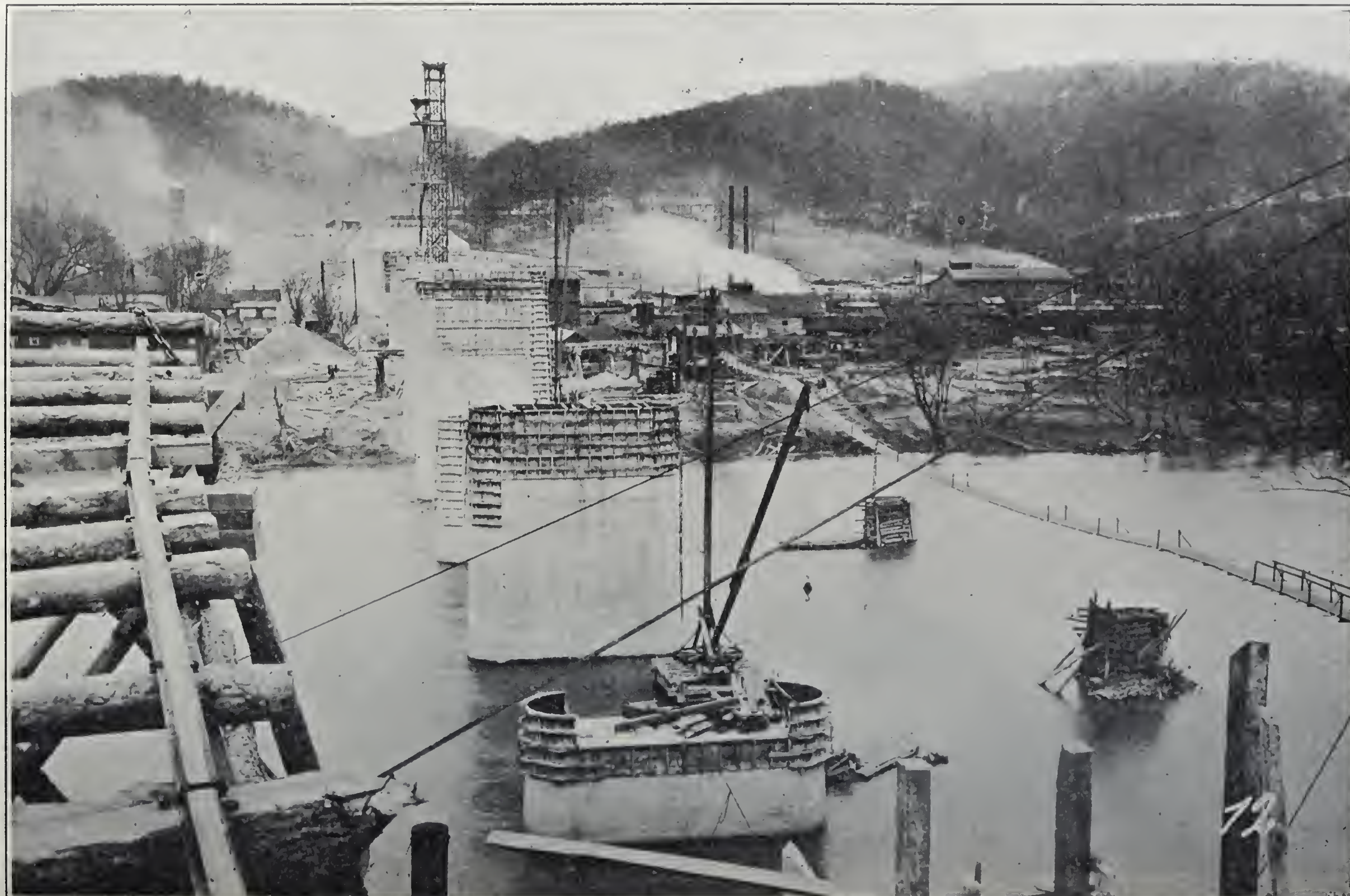


Fig. 56. Magnolia Bridge, Looking East, April 1914.

has shown that the standard tunnel lining as adopted, using 3 in. by 4 in. by 9 in. vitrified shale brick, has been very satistory and almost impervious to the action of locomotive gases.

There were 8200 cu. yd. of concrete used in this tunnel lining, the mixture of which was one part cement, three parts sand and five parts broken stone. Various brands of portland cement were used, all of which were tested by the Baltimore and Ohio inspectors.

All four tunnels on this line have extra large sections for clearance and provision is made for 14 ft. track centers. The arch has a radius of 15 ft. 6 in., the distance from the top of rail to the key-stone of arch being 24 ft. 6 in. On account of handling very heavy Mallet locomotives over this division between the mountain grades of West Virginia and Pennsylvania and Mt. Clare Shops, Baltimore, it is necessary to construct all new tunnels with a maximum clearance.

SIDEHILL WORK NEAR HANSROTE

As noted elsewhere in this paper, a very interesting section of the work extends along the hillside about one and one-half miles in a southerly direction from Randolph Tunnel to Hansrote.

Between those points the new line is located on a bench above and very close to the present operated tracks. On account of the danger to existing traffic, great care was used in prosecuting the work. Over 400 000 cu. yd. of material were removed by force account labor. Drills were used and most of the material was removed with steam shovels by excavating benches about 8 ft. in depth. The material was wasted in ravines at the different levels of the benches and a large quantity was placed on the river side of the present tracks. This will permit the present tracks to be lined out and reduce the maximum degree of curvature from five to three degrees.

Fig. 55 is a view taken April, 1914, and gives a clear idea of the proximity of the sidehill work to the present tracks immediately west of Randolph Tunnel.

STUART TUNNEL

Leaving the operated tracks at Hansrote the new line turns abruptly into the hill and crosses the divide through Stuart

Fig. 57. Magnolia Bridge, Looking East, August 1914.

Tunnel, 3318 ft. long, which is located on tangent except for a spiral within the east portal. The east approach cut of this tunnel required the removal of over 200 000 cu. yd. of rock and about 90 000 cu. yd. of the same material were taken out of the west approach cut. Considerable difficulty was encountered in the west portal excavation on account of the almost vertical dip and badly broken strata.

The average heading section is about 120 sq. ft., but overbreaks developed, increasing this in one place to 185 sq. ft. The strata varies in dip from 45 deg. to considerably under this, the strike being approximately parallel to the center line.

The tunnel was driven from the west portal and two shafts, 117 ft. and 40 ft. deep, respectively. The east approach cut was not completed in time to enable a heading to be driven from the east portal.

The headings were driven as usual, working from five points, and were widened to the full section by hand except for the first 1000 ft. in from the west heading, where a small No. 40 Marion shovel operated by compressed air was used. With this shovel from 60 ft. to 70 ft. of arch were widened and timbered per week, as compared with about 45 ft. by hand. About 6 ft. of bench were taken out by the small shovel at the same time, thus securing ample working clearance. A large No. 60 Marion shovel, also operated by compressed air, was then used in removing the bench and small cars electrically driven were used for disposing of the material. Some difficulty was encountered in establishing the west portal and on account of the questionable character of the material at the east end the heading from the center shaft was driven to within about 70 ft. of the east portal, at which point it opened into two wall plate drifts. The entire arch section was then removed for 30 ft., after which the wall plate drifts alone were driven, leaving the center support for the roof for about 40 ft. in from the portal until the portal was turned. At two places thin strata separated by clay were encountered, and falls occurred which delayed the work considerably.

Both timber and steel forms were used in the tunnel lining, there being over 2200 ft. of the latter used in sections of the tunnel where unstable material was encountered. The metal

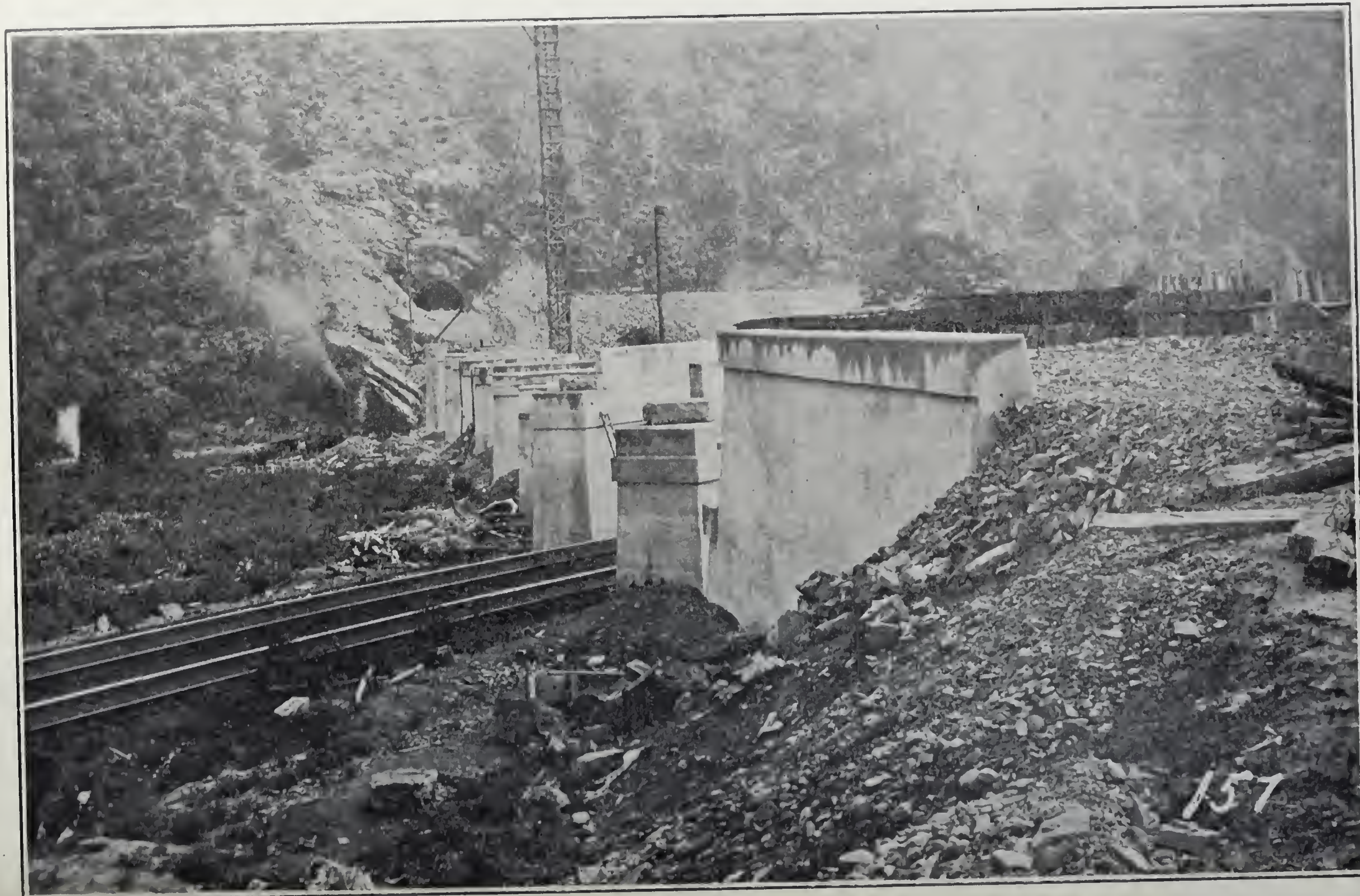


Fig. 58. Kessler's Bridge, Looking Toward West Portal of Graham Tunnel.

arches appear to be a great improvement over the timber in that they reduce the tunnel excavation. They were not removed, the concrete being placed around them. This did away with some packing and increased the strength of the arch. *I*-beams, having a section of 15 lb. per ft. were used in this arching, being placed on 5 ft. to 7½ ft. centers, depending on the character of material to be supported.

As the tunnel excavation progressed and the timber and steel forms were placed, they were followed up by the concrete lining, having dimensions according to the standard section. There were 26 600 cu. yd. of concrete used, mixed with a compressed air operated mixer in the proportion of one part cement, three parts sand and five parts broken stone. As this was the longest tunnel and presented the most difficulties in excavation, it was the last to have the lining completed.

SUPERSTRUCTURES OF POTOMAC RIVER CROSSINGS

The first river crossing is west of Stuart Tunnel at Magnolia. It is about 1000 ft. in length and consists of six 100 ft., three 80 ft. and two 75 ft. deck plate girder spans placed on concrete piers; the new grade is 50 ft. above the old line and about 80 ft. above low water. As noted elsewhere, this bridge forms the east approach to Graham Tunnel, which is 1580 ft. in length and passes through the ridge between the two river crossings.

The second river bridge is at Kessler's curve, immediately west of Graham Tunnel, and consists of four 100 ft. and six 75 ft. deck plate girder spans with three skew girder spans which are over the present operated line. The three skew spans have a combined length of 202½ ft., making a total length of the bridge of 1052½ ft. Foot walks between tracks were provided, as well as refuge bays on each side to provide greater safety to track and bridge men. The 100 ft. girders have a depth of 9 feet, while the 80 ft. and 75 ft. girders have a depth of 8 ft. and 7 ft. respectively. The bridges at both river crossings have open floor spans except the two crossings over the present operated tracks, where solid floors are used for protection against the gases of engines passing beneath on the old line.

The steel work was erected from the shore, without false-

Fig. 59. Kessler's Bridge, Looking West.

work, with a fifty-ton derrick car, which picked up the material from the low level and placed it in position, moving outward as the work progressed. The field riveting was done with compressed air. The structures were designed for *E*-60 loading, B. & O. R. R. specifications for material and workmanship. This will permit, with a large factor of safety, the heaviest engine and train loading in service at the present time. Fig. 57 shows the steel placed on Magnolia Bridge looking east, August, 1914. The town of Magnolia is noted on the West Virginia side of the river and the contractor's power plant to the left of the fill at the east end of the bridge. A total of about 3000 tons of steel were placed, divided nearly evenly between the two bridges.

SUBSTRUCTURES

The piers of both structures were founded on bed rock about 5 ft. below the river bottom. The cofferdams, made with plain sheathing and clay puddling, were placed on the bottom of the river and carried to the height of ordinary high water. The rock substrata lie near the surface at both crossings, so that the foundations did not present any difficulties and no floating plant was necessary. Ordinary wooden forms were used, as shown by Fig. 56, which were made in sections and handled by a derrick as the work progressed.

About 26 000 cu. yd. of concrete were required for piers and abutments, which was deposited mainly from towers located either on the bank or at the first river pier which could be reached by a derrick. The tower at Kessler's crossing was located near the west bank of the river and was 185 ft. in height. In the upper portion of a few of the piers above the reach of the tower, concrete was deposited by compressed air and two of the piers were completed by depositing concrete directly with a derrick.

Revolving mixers, one yard capacity, located on the banks of the river, were used in mixing the concrete, which was composed of one part cement, three parts sand and five parts broken stone. The major portion of the concrete was delivered to the towers by derricks and tramways, elevated and deposited into the various units through chutes. Fig. 58 shows the completed piers, of Kessler's bridge, July, 1914, looking east toward the

west portal of Graham Tunnel. The tower can readily be seen in the view and the tracks of the old line can be seen in the foreground. Fig. 59 shows the same crossing, July, 1914, looking west.

The dimensions of the piers are 8 ft. by 35 ft. under the coping; the batter is ½ in. in 12 in. on all faces. The height of the grade line (top of rail) above low water is approximately 80 ft.

Reinforcement consisted of ¾ in. round rods and 4 in. triangular mesh which were used in all piers above the footings. Vertical rods were placed near the face of the piers and horizontal rods were placed through the piers from side to side and from end to end in layers five feet apart.

In five layers of horizontal rods placed parallel to the center line of the pier, the rods were spaced 24 in. center to center, and in the three corresponding layers of rods passing through the piers from end to end at right angles to the center line, the rods were spaced 12 in. center to center while in two layers a 24 in. spacing was used.

The various stages in the construction of the Potomac River bridges are shown very clearly by Figs. 56, 57, 58 and 59.

GRAHAM TUNNEL

As noted, this tunnel is 1580 ft. in length and is located betweeen the two river bridges. It differs from the Randolph and Stuart tunnels previously described, in that it is driven through stable rock instead of the loose, rapidly weathering material. It was driven by the same methods employed at the other tunnels, drills operated by compressed air and one No. 60 Marion shovel being used. Timber cribbing was placed as the excavation progressed, followed by the standard tunnel lining, using 12 700 cu. yd. of concrete of the mixture—one part cement, three parts sand and five parts broken stone. A revolving mixer operated by compressed air was used in mixing the concrete.

Fig. 60 shows the west portal of Graham Tunnel, August 1914, before the completion of the concrete lining. This view gives a very good idea of the strata underlying this mountain.

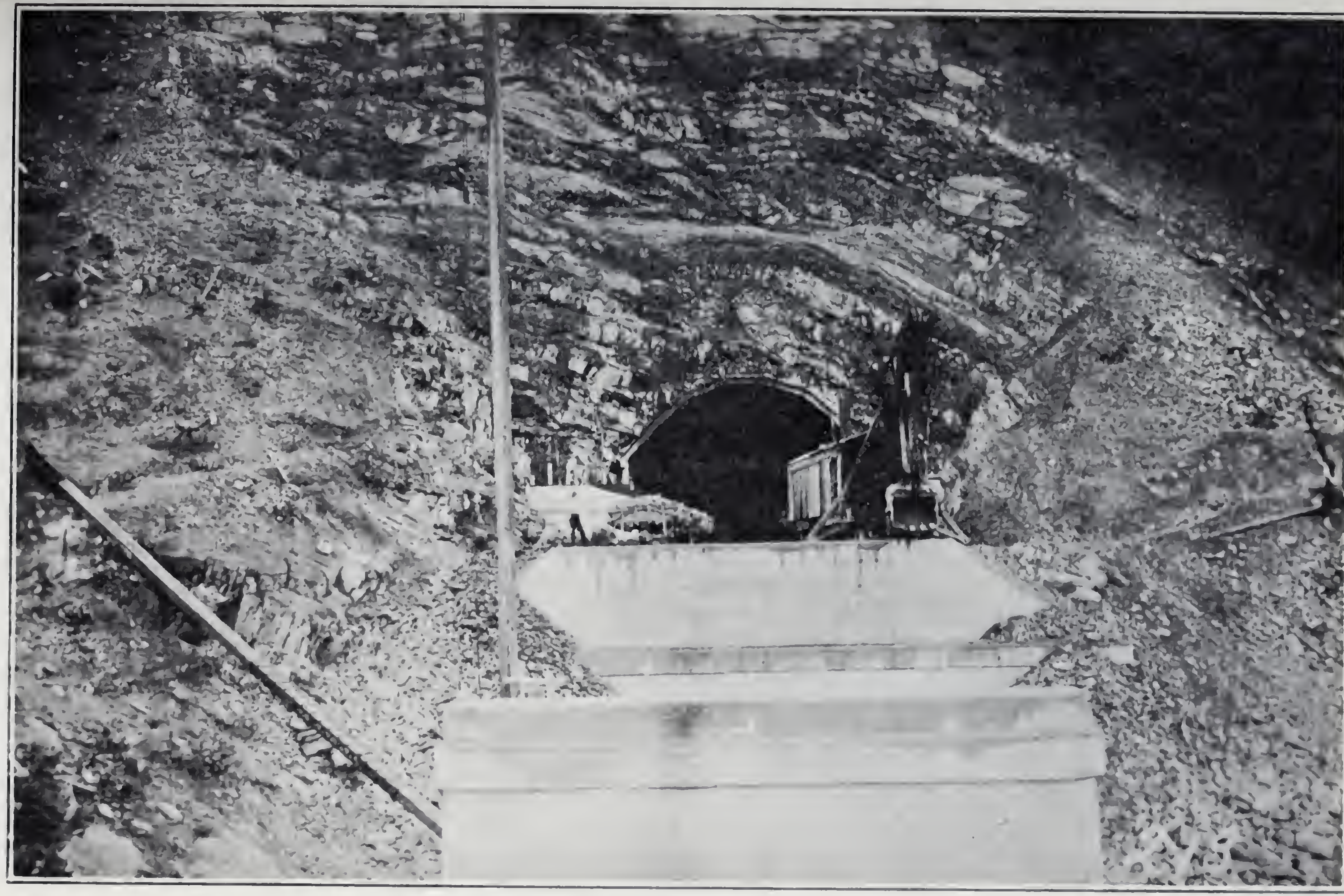


Fig. 60. West Portal of Graham Tunnel.

CONCRETE RETAINING WALLS

Beginning at Kessler's curve, the new line again follows in a southerly direction on a bench along the hillside about 40 ft. above and paralleling the old line for a mile and one-half. Over 80 000 cu. yd. of rock were taken out along this bench at elevations varying from 40 ft. to 100 ft. above the operated line. On account of the hazardous nature of the work, it was handled by force account labor under about the same methods employed east of Hansrote. All of the sidehill cuts were benched in order to prevent slides and to reduce blockading the operated line to a minimum.

To reduce the sidehill excavation it was necessary to construct a retaining wall 1800 ft. in length, located near the west end of the section. This wall is not reinforced and is of gravity section, having a maximum height above the footing of 31 ft. It is 2½ ft. wide at the top and 15 ft. wide at the base. The elevation of the top of the footing was placed at 3 ft. below the top of rail of the lower line. The construction of the footing caused considerable trouble and was extremely difficult at places where it was necessary to excavate to a maximum depth of 14 ft. below the top of footing in order to secure a firm foundation. At other points a 40 ft. rock face had to be moved to secure sufficient room. The top of the wall is 4 ft. above the elevation of the subgrade of the new line.

This inter-track wall is located between the old and new line and required the placing of 22 000 cu. yd. of concrete. It was deposited by a movable traveler which spanned the two operated main tracks and moved on two rails supported on timber blocking. This traveler proved very satisfactory; it was constructed of steel and had a clearance of 32 ft. 9 in. horizontal and 23 ft. 3 in. vertical above the high rail on curves.

The traveler was equipped with two derricks having 50 ft. booms and two boilers and hoisting engines on the upper deck. In this way all of the excavating for the retaining wall footings and all the concrete was handled without interfering with the operated tracks and without any material being moved across the tracks at grade. The derrick located ahead on the platform handled all of the material excavated from the footings while

Fig. 61. Intertrack Wall Between Graham and Carothers Tunnels.

the rear derrick deposited the concrete. The concrete mixing plant was located nearly one-half mile west from the work on account of insufficient room nearby and the material was carried to the traveler in small cars which were picked up and emptied into the forms. A cantilever projection from the traveler supported the wall forms which were of steel and their position relative to the traveler was regulated by turn-buckle adjustments in the vertical and horizontal supporting rods. As the forms were moved ahead from one section of the wall to the next, they were lifted free of the completed work. The wall was built in 50 ft. sections. The concrete mixture consisted of one part cement, three parts sand and five parts broken stone.

With the necessary foundation excavation work and shifting and adjustment of traveler and forms, about two 50 ft. sections were completed per week. At the joint between each day's pouring a bond was secured to the adjacent rock face. The new roadbed was back filled behind the wall as it was completed. About 4000 cubic yards of concrete were placed per month by the traveler during the construction of the wall without interfering with the traffic, although the train movement was almost continuous at this point. Fig. 61 shows the inter-track wall as completed July, 1914, and the traveler after it had been dismantled.

CAROTHERS TUNNEL

A short distance west of the inter-track wall the new line diverges from the operated line and passes through Carothers Tunnel, which is 1000 ft. in length. The material excavated from this tunnel and the method of driving was similar to that of the other tunnels on the Improvement. One No. 60 Marion shovel and drills operated by compressed air were used.

Timber cribbing was placed as fast as the excavation progressed, and this was followed up by standard concrete lining, requiring 8000 cu. yd. of concrete which was of the usual one-three-five mixture.

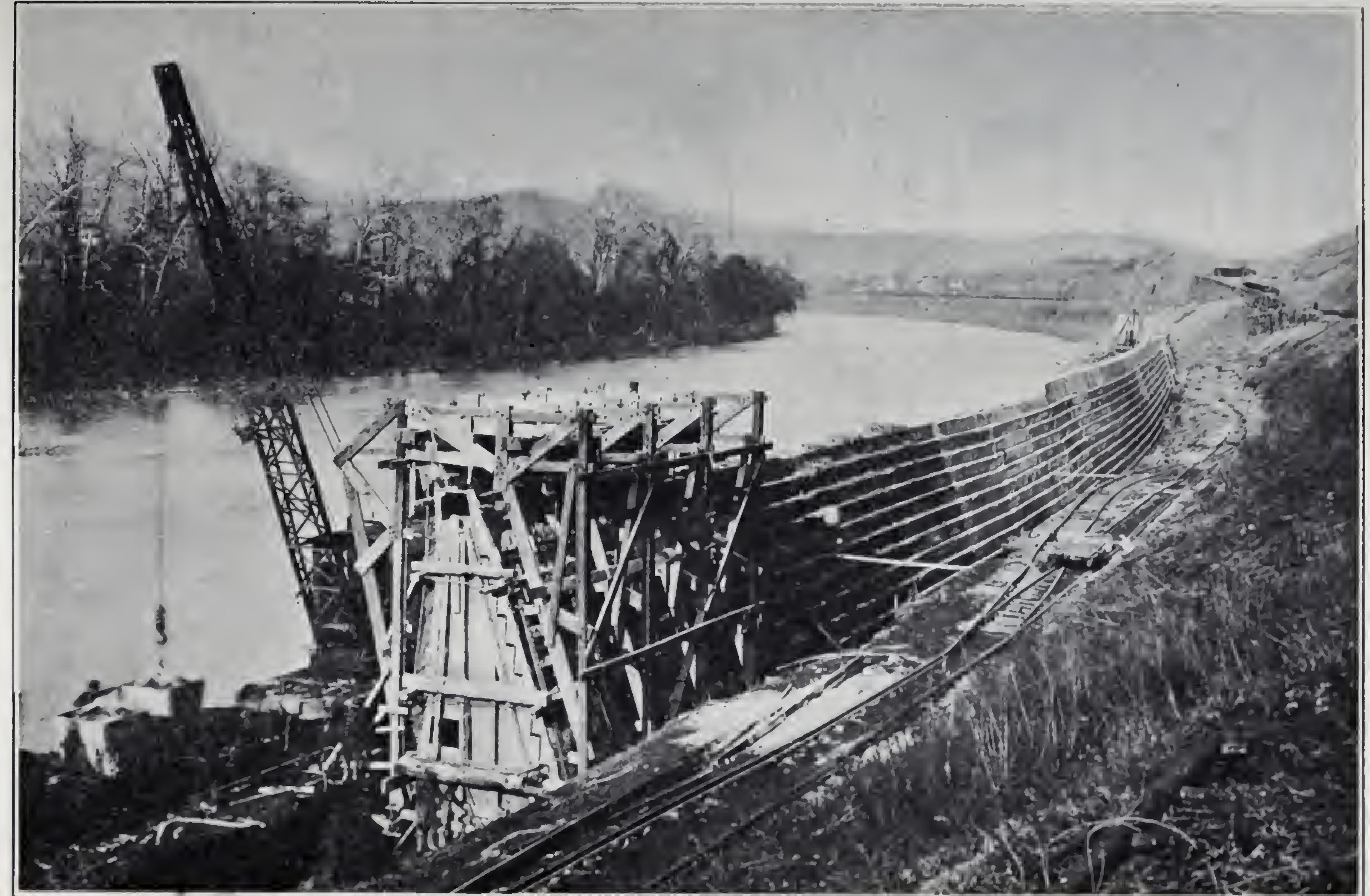


Fig. 62. River Wall West of Paw Paw, Looking East, December 1913.

PAW PAW CUT

One of the largest cuts on the line is that along the southerly edge of Paw Paw. The maximum depth on center line at this point is 96 ft. Over 500 000 cu. yd. of material were removed, the greater part of which was earth. It was hauled west about one and one-quarter miles to a point where the old line was raised about 7 ft. and shifted towards the river in order to make room for a four-track line without disturbing the rock hillside. This improvement, at the same time, places the grade of the old line above high water.

With the exception of the Potomac River crossings, the only steel bridge on the line is an overhead highway structure crossing Paw Paw Cut near the town. There are two 12 ft. and two 8 ft. concrete arches on the line and several smaller openings. There are no highway crossings at grade.

RIVER WALL

A portion of the new fill, referred to above, extends to the river. In order to protect and at the same time without encroaching on the stream, another retaining wall similar to that east of Paw Paw was constructed. This wall is 3100 ft. in length, has an average height of 24 ft., width at top of 2½ ft., width at base of 15 ft. It required about 23 000 cu. yd. of concrete, which was mixed with a rotary mixer—one part cement, three parts sand and five parts broken stone. The wall being next to the river it was not necessary to span the operated tracks and only a wooden traveler was provided for shifting the forms. The concrete was deposited with a locomotive crane. The forms were of steel and built in 30 ft. sections, two sets were provided, which were used alternately.

Fig. 62 shows this wall under construction December, 1913, with a section of the forms in place, and Fig. 63 shows the completed wall.

RAIL USED

The new line is being laid with 100 lb. A. R. A. Section *B* rail, Fig. 10, rolled by the Maryland Steel Company, 1914; about 25 percent of the rail was made by the open hearth process and will be used in special places, while the remaining

Fig. 63. River Wall West of Paw Paw, Looking West, April 1914.

75 percent is Bessemer steel; track centers will be 14 ft. and No. 16 crossovers will be used throughout.

In order to conduct an experiment with reference to the use of rail, ties, tie plates and spikes these materials will be used as follows.

1. Nine miles double track No. 1 white oak untreated ties with cut spikes and narrow base tie plates.

2. Two miles double track; treated ties, bored for screw spikes with wide base tie plates.

3. One mile double track treated ties bored for screw spikes with plain reinforced angle bars.

The ties will be placed 22 in. between centers and on about 18 in. of trap rock ballast.

CHANGES IN THE PRESENT LINE

As indicated, the operated tracks were changed at several places, introducing curvature of larger radius and also revising the grade to conform with that of the new line. The revisions were as follows:

1. Beginning at a point 1000 ft. west of the inter-locking tower at Orleans Road, the roadbed was raised to make a four-track line with the new line to a point 500 ft. west of the west end of Doe Gully Cut.

2. Between Doe Gully Cut and Hansrote the operated line was shifted towards the river to lighten the 5 deg. curve and substitute a 3 deg. curve.

3. At Kessler's curve the waste material from the new line was utilized to make an embankment along the Potomac River, and to provide a roadbed for a 7 deg. curve in place of the 9 deg. curve on the existing roadbed.

4. From a point 1000 ft. west of Paw Paw a new double track roadbed for the operated line was constructed along the westbound side of the latter in order to permit the construction of the new line without disturbing the rock hillside.

With the completion of the new line it is proposed to provide the following facilities:

1. Doe Gully: Interlocking plant to handle switches for standard four-track layout.

2. Magnolia: Interlocking plant to handle crossovers for the two double-track lines.

3. *Little Cacapon:* Additional functions to be added to inter-locking tower to handle the four-track movement east of that point, and westbound pocket.

4. *Great Cacapon to Doe Gully:* Automatic signals with lock and block on one track.

5. *Doe Gully to Little Cacapon:* Automatic signals with lock and block on one track of the eastbound line.

6. *Rockwells Run:* Water station to replace the one now in use.

The total force employed was approximately 2500 men.

The work on the cut-off is gradually drawing to a close and by the end of this week the grade will have been completed with the exception of the final elimination of Doe Gully Tunnel. One track is nearly completed, the helper station will be abolished, and eastbound freight trains operated over the new line by the 1st of December (1914).

CONTRACTORS' PLANT

The magnitude of the Magnolia Cut-Off work required a large and thoroughly equipped contractors' plant.

The equipment aggregated on the entire work the following pieces:

		Number
Shovels—Steam or Air		
Marion	No. 20	1
Marion Osgood	No. 40	1
Marion Osgood	No. 50	1
Marion	No. 60	17
Marion Osgood	No. 60	1
Bucyrus	No. 73	1
Total		22
Locomotives		
Size of Cylinders 10 in. 16 in. and 12 in. 18 in.		55
Locomotive Cranes		2
Dump Cars, about 4 cu. yd capacity		550
Concrete Plants, revolving mixers, 1 yard capacity		6
Travelers spanning present tracks for inter-track wall		1
Drills		
Air drills		64
Air Jap drills		2
Steam drills		46
Steam Jap drills		4

Power Plants

Magnolia	1
Doe Gully	1

On most of the sidehill work steam drills were used while air lines were installed for the tunnel work and Doe Gully Cut.

At Magnolia one power house was supplied with two compressors, each capable of compressing 1644 cu. ft. of free air per minute, at 80 lb. pressure, to a 6 in. distributing pipe line about 11 500 ft. long. The other equipment consisted of six 100 h. p. boilers and two D. C. generators having a total capacity of about 200 kw. for lighting current at 250 volts. There were two sawmills and a forging and blacksmith shop of considerable capacity located at Magnolia.

The Doe Gully power plant consisted of four 100 h. p. boilers and two 75 h. p. boilers, two air compressors and one 50 kw. generator. The air compressors would compress 1644 cu. ft. and 1000 cu. ft. of free air per minute respectively.

Suitable camps were provided to house laborers and other employes at Doe Gully, Hansrote, Magnolia, Kesslers and Paw Paw, particular attention being paid to sanitation and good quality of drinking water. Electric lights and modern fixtures were provided in the camps and on the work wherever possible to facilitate the work and add to the comfort of the employes.

MEASURES TO PREVENT ACCIDENTS AND PROTECT TRAFFIC

The larger portion of the work being located adjacent to a busy railroad, where the traffic is almost continuous in each direction and in a mountainous country, it was necessary to take measures to prevent workmen from being struck by the trains. Foot paths were constructed on the outside of the operated tracks, either on the shoulder of the fill where the bank was too narrow or on trestle construction. All employes were required to use these paths instead of walking on the tracks, and special instructions were printed which all employes were required to read and sign.

A policing system was organized by the railroad of uniformed and plain clothes men who made it a special duty to see that the instructions were obeyed and to keep trespassers off the property.

Great care was taken also to protect traffic on the railroad; an operator was provided who was in constant communication with the dispatcher, and all blasting was done under strict control and inspection. 40 percent dynamite being used. No shots were fired without learning the location of trains. Flagmen were also sent out in both directions in advance of each shot. Powder inspectors were provided to personally inspect the loading and firing of each shot so as to reduce to a minimum the danger of blockading the tracks below. Vigilance was the order of the day, and men with wheelbarrows were stationed at the foot of the slope under the steam shovels to remove the small pieces of rock from the toe which it was found impossible to keep from falling; these were carted to the riverside.

Very few fatalities have occurred compared with tunnel construction work prior to this time, where the number of casualties has averaged one man for every 500 ft. driven. This, however, has not been the case at Magnolia.

Extremely few delays to trains have occurred which is one of the results of close supervision by the railroad employes in charge of the work and precautionary measures taken by the contractors. The work has been followed on schedule time, and expectations as to the completion of the improvement will be met. One track for eastbound freight will be put into use ahead of time.

DIVISION OF CONSTRUCTION WORK

To facilitate construction, the work was divided into eight sections, which were let to different contractors. The work on some of the sections was divided and sublet to contractors who had better equipment and probably more experience in handling the particular class of work required.

Beginning at the east end, the contractors on this work were:

Section No. 1 and part of No. 3.
Kefauver and McLaran. Baltimore, Md.
Sections No. 2 and No. 4 and part of No. 3.
H. S. Kerbaugh, Inc., New York.
Sections No. 5 and 7.
Bennett and Talbott, Greensburg, Pa.

Part of Section No. 6.
Sheesley and Janney, Johnstown, Pa.
Parts of Sections No. 6 and No. 8.
Smith-McCormick Co., Easton, Pa.
Part of Section No. 8.
The James F. McCabe Co., Baltimore, Md.
The American Bridge Company fabricated and erected the two bridges across the Potomac River.

The work was done under the direction of:

Mr. F. L. Stuart, Chief Engineer.
Mr. H. R. Talcott, Engineer of Surveys.
Mr. H. A. Lane, Assistant Engineer of Surveys.
Mr. J. T. Wilson, District Engineer.
Mr. E. M. Graham, Mr. T. C. Marshall, Mr. T. Ellett, Jr., Resident Engineers.

CONCLUSION

The construction of the Magnolia Cut-Off completes a program or budget of improvements on the Baltimore and Ohio which was authorized and started by President Willard in the early part of 1911. Most, if not all, of the various improvements were problems difficult to solve. Among these the Magnolia Cut-Off Improvement was the last, and undoubtedly the most difficult, and had been before the executive and operating officers of the Baltimore and Ohio for the past fifteen years. The congestions in the vicinity of Magnolia, and principally on the Hansrote helping grade, have been a stumbling block to the operating officers for many years, the results of such congestions being far-reaching and frequently influencing the movement of coal out of the coal regions, as well as hindering the prompt dispatch of fast freight between distant cities. You may appreciate the relief felt by the management when nearing the completion of this important work.

The Engineering Department has been able to so regulate the progress of the work being handled by each of the seven contractors that each will close out his section at about the

same time and the entire work will be completed as a unit; this is considered quite an achievement. The Improvement has also been carried on with such progress that it will be completed three weeks earlier than the originally estimated time. The cost of the work to date is below the estimate, and the present indications are that the total expenditure will be $200 000 less than the total estimate of $6 000 000. At several points it was possible to make connections with the old line which enabled the construction of tracks as fast as the grading was completed so that now it only remains to connect the various sections in order to get a continuous track over the new line. The entire work from the standpoints of cost, hindrance to traffic and time of completion has been successfully carried out, and to the satisfaction of the management.

THE TREND OF MODERN BLAST FURNACE CONSTRUCTION

A. E. Maccoun*

There are many important details to be considered in connection with the construction of a modern blast furnace plant. The one of first importance is the furnace proper and its stocking equipment, which will be considered from the delivery of the raw materials to the plant, the unloading of same in stock piles, or in furnace bins, their transfer from bins to larry cars, and from thence to furnace skips, or hoists, together with their final delivery into the furnace stack.

Other details will also be considered, such as the economical removal of the iron and slag; gas washing; hot blast stoves; and the power equipment required, consisting of blowing engines, pumps, electric power stations, etc. The development and use of electric power has been one of the greatest aids in modernizing blast furnace plants, as it is only through the use of the electric motor that many of the newer labor saving devices at present in use around modern blast furnace plants could be attempted.

A great amount of study has been expended on blast furnace construction, not only towards improving the quality of the product and reducing the operating expense and cost of production as much as possible, but in an endeavor to make this class of work safer and more pleasant for the men employed.

The process of smelting iron in a blast furnace consists of charging a suitable mixture of coke, ore and flux into the top of the furnace and blowing a current of heated air in at the bottom. The oxygen in the air blown consumes the fuel forming heat for the chemical reactions and melting the products, and the reducing gases formed help to remove the oxygen from the

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ore in their ascent through the furnace charge, any unreduced ore which remains being reduced by the carbon of the coke. The gaseous products pass out of the top of the furnace, and the liquid products of iron and slag are drawn off at the bottom.

For the successful management of a modern furnace plant, a thorough technical knowledge, not merely chemical, but mechanical and electrical, is required, as the modern blast manager has not only metallurgical problems to solve, but questions of transportation, power generation and transmission, construction, etc., all of which indicates how varied this class of work has become.

UNLOADING RAW MATERIALS IN STOCK PILES, FURNACE BINS, LARRIES, ETC.

This problem must be studied not alone with the idea of obtaining low costs for handling materials, which cost is made up of labor, transportation, power costs, etc., but also with reference to what is of equal if not greater importance, the delivery of these materials to a blast furnace as nearly uniform as possible in quantity and composition, so as to obtain the best furnace practice.

With the ores used in the furnace burden this is done before shipment by a very thorough system of mixing the ores from the mines so that the resultant material shows only slight variations during the entire season.

The various cargoes of each particular ore further undergo an additional mixture as they are unloaded into the furnace stock piles by the ore bridges, so that any portion of the pile may be fairly considered representative of the season's average ore shipment. This system results in the elimination of one of the variable conditions confronting the furnace man, that due to irregular composition of ore, and helps greatly in attaining uniform operation.

In order to still further aid in obtaining a more uniform mixture both chemically and physically for the coke and limestone as well as the ore, bin systems of the most improved type are being designed. On inland furnaces the first unloading is accomplished by means of car dumpers, ore bridges, and systems of automatic dump, electrically operated transfer cars, carry-

ing ore to stock piles or furnace bins; and on lake furnaces by Hewlett unloaders or Fast plants, in connection with ore bridges, which are used in transferring ore from vessels to stock piles and furnace bins. By this class of equipment not only are operating costs reduced, but as mentioned before, greater uniformity and more regular mixtures of the raw materials are obtained.

Modern bins should be in sections of suitable length for dumping cars and of large capacity, so as to obtain better mixing, and thus keep a large stock of the various raw materials on hand in case there should be any temporary shortage in the supply. Having this large capacity is also an advantage in not requiring an unloading force on the trestle during the night shifts. There should be at least two unloading tracks over the top of the bins, preferably three, arranged so that one of them can be used solely for transfer car service. It is an advantage to have grizzley screens on top of ore and limestone bins with 12 in. by 12 in. openings, so as to prevent excessively large lumps going in and plugging up the chutes, as better distribution is obtained by breaking this large size material. These screens also prevent such debris as timbers, etc., collecting in the bunkers and plugging up the chutes.

The proper design of a blast furnace bin is a very important detail, as the material to be handled is irregular in size, and is often wet and sticky, making it hard to flow uniformly out of the gates in the bottom of bins. This is particularly so with ore and limestone. Unless the material in a bin works down evenly through its whole area, a large additional expense is entailed in its operation, giving constant trouble, and causing delays and irregularities in charging. It is also important when dumping material into bins that there is no tendency to the segregation of the coarse and fine materials in the bin itself, or in drawing the stock from the bin chutes into the larry cars. Any tendency for materials to flow in such a way as to cause this separation should be strictly avoided, as it will cause bad distribution and impair the furnace practice.

The proper design of chutes and gates is of equal importance, as the operator must have absolute control when drawing materials from the bin, so as to obtain correct weights. The

chutes and gates should be practically continuous on the bottom of bin, with the exception of allowing for clearance. Thus there will be a minimum space between each chute for material to build upon, and the bin can be evenly worked along its whole length. These details being taken care of, and with angles steeper than 45 deg. for the bottom or sides, good results should be obtained. The Hoover & Mason and the McKee types of bins have given excellent results, considering not alone low stocking and charging costs, but the good distribution results obtained from them as well.

Large capacity larry cars are being used between bins and skips, and the design of these cars must be carefully studied in order to find one in which there is no tendency for separating the coarse or fine materials, either in the larry, or on their passage from the larry to the skip bucket, as it is fully understood the damage that will be done to the distribution if any such classification takes place. The great importance of this point will be taken up later. Recording scales on larry cars are important features to obtain more accurate weighing. Greater economy is obtained from large size larry cars, both in labor and power, on account of the fewer number of trips required; also there is much less labor and material expended in repairs. In some cases a modern larry car will hold a full charge of ore and limestone, and a modern 500 ton furnace can be operated with a single man per turn on the larry between bunkers and furnace skip.

On the coke bunkers efficient screens should be installed for removing coke dust before charging coke into the furnace. Also an economical arrangement should be made to remove this dust from the stockyard. The charging of large quantities of coke dust is very injurious to good furnace practice.

THE MECHANICAL CHARGING OF A BLAST FURNACE

There are two principal systems used in elevating the stock to the top of a blast furnace. The first is what is known as the Neeland method, in which the stock is run from the bins into round buckets, with bottom consisting of a cone or bell attached to a rod running up through the center of the bucket to a hook on the top. This bucket is taken to the bottom of

hoist incline and sent up, hanging from the hook at its top. When it reaches the top of the furnace it is seated and its contents are dumped on the big bell by lowering the hook on the central rod carrying the bell, which acts as a valve. There is less breakage of coke due to handling in this style of top.

This method developed some weakness from a metallurgical standpoint owing to the fact that the buckets always went under the chutes in the same relative position, and as the ore left the bins the lumps were piled against one side of the buckets, injuring distribution. To eliminate these irregularities in the raw materials coming from chutes, arrangements were made to rotate the buckets.

This is accomplished in various ways. In some cases it is done on the car after being filled at the bunkers, or on a turntable in the skip pit. In others the bucket is not removed from hoist, but is fed by larry cars in the usual way, and then turned on its hanger to a definite angle for each lead. It is impossible at this time to go into these various details further.

The other system which is used on the majority of furnaces consists of the use of a rectangular skip bucket on wheels, running from a pit beneath the floor of stockyard up an incline to a hopper above the furnace top, where it turns upside down and dumps, and then returns to the bottom. In some cases one skip bucket is used; in others a double track skip with two buckets is employed, in which case no counter-balancing is necessary.

All of these systems are designed to remove as many irregularities in distribution as possible, or to compensate for the various irregularities. The skips should be dumped at about a 60 deg. angle, so as to dump the material rapidly; they should dump at a central position to the dumping hopper, at the same angle, and at exactly the same speed each time. The electric skip hoist can be easily adjusted to dump in this manner; this type is also very much more economical in the use of power. With stationary tops the material must be properly dumped on the small bell to get good distribution. The double skip permits slow speed with skip cars; skip buckets should be of suitable capacity.

The dumping hopper should be made with as steep an angle as possible and should be of sufficient capacity to hold two skips of coke. The throat should be from 36 in. to 48 in. in diameter, and approximately 60 in. high, as with this type of top better distribution is obtained if a skip load of ore and limestone does not overfill the throat, and partially fill the dumping hopper. It is important not to have too long a throat on account of the fall causing excessive breakage of coke.

Electrically operated bells are giving most satisfactory results and are very much more economical in the use of power. The large bell should have an angle of from 50 to 55 deg. to keep itself clean and to prevent ore from sticking on its surface and impairing distribution. In some cases it is found to be an advantage to finish its surface all over. Its diameter should be about 3 ft. 6 in. smaller than the throat of the furnace when no distributing ring is used. In some cases the installation of distributing rings, such as the Killeen Distributor, has resulted in better furnace practice. It is often necessary to try different sizes of bells and distributors, etc., in order to compensate for other irregularities and to obtain a better working furnace.

It is important to reduce the mechanism on top of furnace stack to a minimum. Any good skip-filled top, with the skip dumping at the proper angle, central to the dumping hopper, the small bell hanging true to center and lowering perpendicularly so that the material is distributed around the large bell equally in regard to amount and in the proportion of coarse and fine, should give good results. In some cases rotary tops give improved distribution, but it has not been shown that the results obtained from rotary furnace tops have produced any improvement over the showing made by stationary tops. If care is taken in the handling of the raw materials and sizing can be prevented in bunkers, and from bunkers to larrys and skips, etc., the rotary top should not be necessary. The simpler a furnace top is designed the better it will be.

Stock line protection is being secured by the use of various good arrangements of wearing plates, which are giving excellent satisfaction. There are many other interesting details on furn-

ace top construction, but I can only review briefly some of the most important details.

Figure 1 gives an elevation through a blast furnace and stockyard, which shows many of the details mentioned.

THE IMPORTANCE OF GOOD DISTRIBUTION OF THE RAW MATERIALS

Mesaba ores being very easy to reduce, it follows that when carrying a large percentage of these fine ores the greatest care must be taken to distribute them to the best advantage in a furnace burden. Owing to the tendency of the Mesaba ores to pack closely, the ascending gases do not percolate through the burden readily with these fine ores, and try to find as easy passages as possible. When this takes place the ascending gases do not come in contact with the ores evenly over the whole surface included across the horizontal sections of the furnace, and some of the ores will not be thoroughly reduced by the gases. This will cause an increased coke consumption on account of the carbon required to reduce this ore, because it requires partial direct reduction. These irregularities are also augmented by any irregularities in charging or the arrival of large quantities of material in a state of fine mechanical division, giving rise to an interruption in the uniform upward flow of the gases. This is one of the important reasons why soft coke, coke dust, limestone dust, etc., should be thoroughly eliminated.

Keeping in mind all of these conditions in blast furnace design we are greatly aided in securing a blast furnace from which we can obtain good furnace practice.

HEARTH CONSTRUCTION

Very much more substantial hearth jackets are being used. The preference is for cast steel or cast iron jackets with water cooling pipe coils cast into each segment of jacket. This type of jacket should extend well below the hearth line, this distance being at least four feet. These jackets are heavily banded with steel bands and are absolutely tight, thoroughly water-cooled and strong enough to resist the expansion of brickwork, as a result almost eliminating the danger of severe breakouts. Ditches around the outside of this type of jacket are not used,

the brickwork being built up solid against them, both inside and outside.

Some furnace operators prefer a jacket of heavy riveted steel plate of ample strength, water sprayed, and with a ditch around it; but the former arrangement has given most satis-

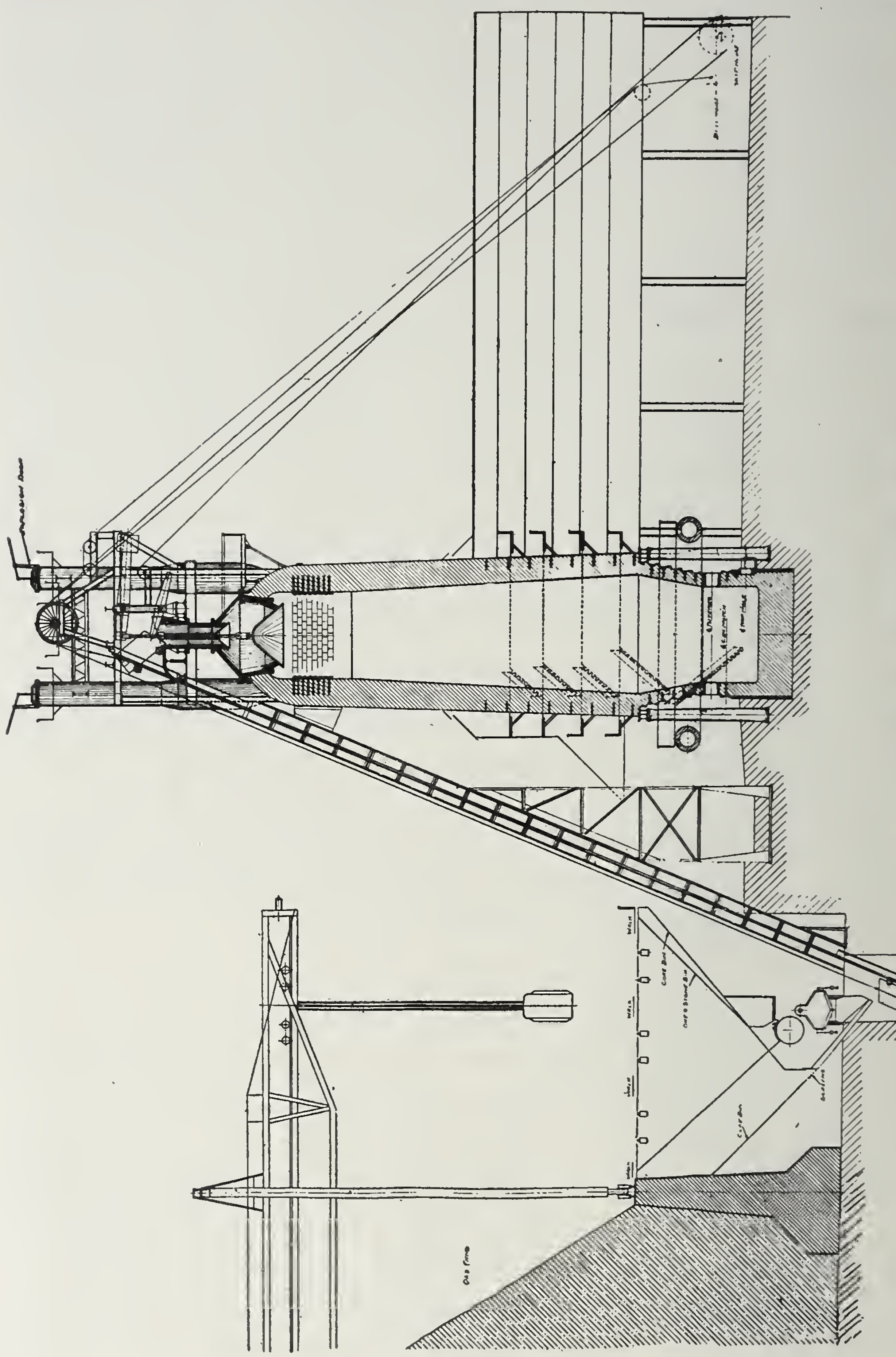

Fig. 1. Sectional Elevation.

factory results and is coming into more general use. It is preferable to avoid the ditch, if possible, for reasons of safety.

In the cast jacket a bronze cooling plate is placed through the jacket about three feet above the bottom of tapping hole.

The trend of development is along the lines of larger hearths and lower boshes. For a 500 ton furnace the usual practice is a hearth diameter of from 17 to 18 feet; bosh diameters 22 to 23 feet; a comparatively low bosh of from 12 to 14 feet, the bosh angle being between 79 and 80 deg. The bosh, of course, can be too low, the ideal bosh should start just below the top of the zone of fusion, and to a certain extent is determined by the conditions under which the furnace is to be operated, i. e., ore burden, blast temperature, total blast volume, etc.

BOSH CONSTRUCTION

The construction of the bosh has been greatly strengthened. On large Mesaba furnaces the water cooled steel plate bosh with sprays or buckets has not given good results, but it is satisfactory on many of the smaller furnaces.

The bosh usually preferred is protected by bronze cooling plates and heavily banded to supply the necessary circumferential strength, the style of plate used varying. Some prefer the Scott plate; others, the Gayley plate; while others use modifications of these plates to suit their conditions. The methods of using these plates also vary. Some use one standard plate in the bosh, varying the numbers in a row, depending on the bosh angle. Others keep the same number of plates in each row and use various sized plates.

Different styles of construction are also used in placing the cooling plates in the bosh, such as brick arches, cast iron boxes, and others bricking in the plates solidly without arches or boxes.

These details vary greatly, but it is important to secure the maximum strength of bosh, and not to overcool it, as a very poor-working furnace may be the result of too much bosh cooling.

The number of rows of cooling plates above tuyeres to mantle varies from five to seven rows. For the ordinary short bosh that is usually preferred, six rows should be sufficient.

The steep bosh angle, approximately 79 deg., is preferred; also the short bosh, as the short and steep bosh reduces the tendency to hanging and brings about a more uniform descent of the charge to the hearth.

A varying number of tuyeres are used. It is better to run a furnace with such a number that they can all be kept open, rather than having some plugged up, as results are more regular. Twelve tuyeres is a very suitable number; some operators, however, prefer a few more than this. There are some very satisfactory arrangements of tuyere breast construction of steel plate, cast steel or cast iron, reaching from hearth jacket to first row of plates above coolers.

The best diameter and length of tuyers to use should be determined from the working of the furnace and its ability to keep its bosh clean.

FURNACE STACK

Furnace shells of heavy steel plate construction are being used. The thin lined shell, either sprayed or cooled with water buckets, has not been, on the whole, as successful as was hoped for, as excessive cooling is liable to take place. As long as the brick remains in the stack good results are obtained. When bricks wear out and the lining gets back to the shell, heat is lost by conduction, etc., and coke practice increases. This type of furnace does very well on Spiegel, Ferro Manganese, Ferro Silicon, etc.

The usual construction preferred is a heavy riveted steel plate shell with the brickwork laid directly against it with no packing space, with a lining of medium thickness, approximately 36 in. In some cases cooling plates are used above the mantle to advantage, but these should not extend to the inside face of the lining, and are preferably kept 18 in. back, for in many cases in which they were extended to the face of the lining it was a very serious proposition. Their use is often an advantage in helping to extract some of the heat from the inwall and thereby increasing the resisting qualities of the brick to heat and to erosion by the gases. The batter of furnace stacks has been increased and is now preferably as near 1-inch per foot as possible, and should begin at the stock line.

The height of furnace preferred for our Mesaba ore practice lies between 90 and 100 feet, depending upon conditions.

Studies have been made of the quality of fire brick best suited for furnace linings, their resistance to erosion by the furnace gases, and abrasion by the stock. In this connection porosity, density, melting point, conductivity, abrasion, and spalling tests have been made, and the effects studied of various percentages of calcined flint, flint, and plastic clays, together with the influence of the weathering, grinding, and coarseness of material in relation to the above qualities.

SHAPE AND POSITION OF OFF-TAKES AND EXPLOSION DOORS

Vertical up-takes are taken off the furnace shell as high above the stock line as possible, preferably at four points equally spaced on the circumference. Safety explosion doors to allow relief on slips, but which do not allow large material to be thrown out of the furnace, should be placed on top of the uptakes. Downcomer connections are taken off part way up on up-takes to reduce flue dust and return as much material as possible to the furnace on slips It is important to have these gas openings of sufficient area, so as to keep down the velocity and to prevent too much back pressure on the furnace. These off-takes are usually arranged so as not to be directly over the tapping hole, cinder notch, or entrance of blast main to bustle pipe, as a furnace is always more active at these points. and this helps to prevent channelling and gives a more even distribution of the gases in their ascent through the stock in the furnace.

THE USE OF WASHED GAS FOR BLAST FURNACES

The installation of modern gas washing plants has permitted improvements in design of hot blast stoves and gas burners that could not have been attempted with dirty gas.

The usual practice for a plant containing several blast furnaces is to use an efficient dust catcher on each furnace and at times additional auxiliary dry dust catchers, or dry cleaners, so as to catch as much of the heavy material sent over with the blast furnace gases as possible, as this material is valuable and can more easily be taken care of in the dry state. From here

the gas is collected in one central dirty gas main and from this main conducted to the washers, or it can be used directly as dirty gas in emergencies. This arrangement tends to equalize the variations in the composition and amount of gas given off by the different furnaces and better and more regular results are obtained.

The most important point in all gas washing processes is to cool the gas sufficiently to precipitate the moisture and eliminate it from the gas. To do this effectively it must be brought in contact with the water quickly and as intimately as possible and the washing apparatus must be of such design that the water distribution in it will thoroughly flush the dirt away and prevent its building up and requiring frequent cleanings.

The dirt removed from this gas is of such a nature that it builds up very rapidly and becomes very hard and difficult to remove from the lines, etc., if only a small amount of water is brought in contact with it.

In the earlier installations, nozzles and sprays of various designs were installed in the mains leading to the washing plants, and as the water was insufficient to thoroughly remove the dirt, the lines were soon filled to a point that required cleaning. This led to removing such devices from the gas mains altogether and delaying all of the wet cleaning until the washer proper was reached, where it is introduced in the manner mentioned.

The baffle type was the first and most natural type to be tried, in which plates of various shapes were inserted in the towers in such a manner that a film of water, introduced through nozzles in the top of the towers, ran from one to the other while the gas passed in the opposite direction, breaking through the film of water at each baffle, and giving up its dirt which was washed down to the water seal under the tower. This was soon found to be inefficient due to the fact that the water and gas were not brought into intimate enough contact to thoroughly remove the dirt and give the desired degree of cooling.

While, of course, the ideal condition for blast furnace stoves or boilers would be a hot gas containing neither dirt or moisture, very good results will be obtained with a dirt content in the gas of 0.15 of a grain per cubic foot and a temperature

of about 70 degrees, which corresponds to a moisture content of 8 grains per cubic foot at saturation.

In the more modern types of washers the spray tower has replaced the baffle tower and the results obtained are such that it will continue to be the most satisfactory solution for the rough or primary cleaning.

The spray tower differs from the baffle tower, in that the entire cross-section is given to cleaning the gas and the baffles are replaced by screens located every few feet up the entire height of the tower.

The water is introduced in the shape of a spray at the top, while the gas enters at the bottom, still allowing the washer to work on the counter-current principle, as in the case of the bafflle, but with a much better opportunity to mix with the gas, the advantage being that no opportunity is given for the tower to block up with dirt at points and cause the gas to channel.

The method of spraying the water in such a tower is important, and there are several forms in use from a mechanically operated valve furnishing periodical jets of water, as in the Diehl washer, preventing the gas from channelling, to the simple water jet impinging on a flat or concave surface. Both of these types are simple and effective. When the gas leaves these sprays it is, or course, saturated and the moisture contained will depend on its temperature at this point, and in a well designed plant this can be maintained within three or four degrees of the cooling water used, if so desired. The towers are usually designed to give a velocity of four or five feet per second to the gas traveling through them.

In the earlier installations the towers were allowed to dip into a basin at the bottom and thus form a seal to prevent escape of gas and a basin in which to collect the dirt removed from the gas. On the later types the bottom ends of the towers are fitted with hopper shaped bottoms and outlet bends that allow the dirt to be continuously removed with the water, and at the same time prevent the escape of gas due to loss of water.

This makes the unit entirely self-cleaning. The overflow water from the towers is allowed to run to settling basins, where the dust settles out and is later removed by a grab bucket suspended from a crane over the basin.

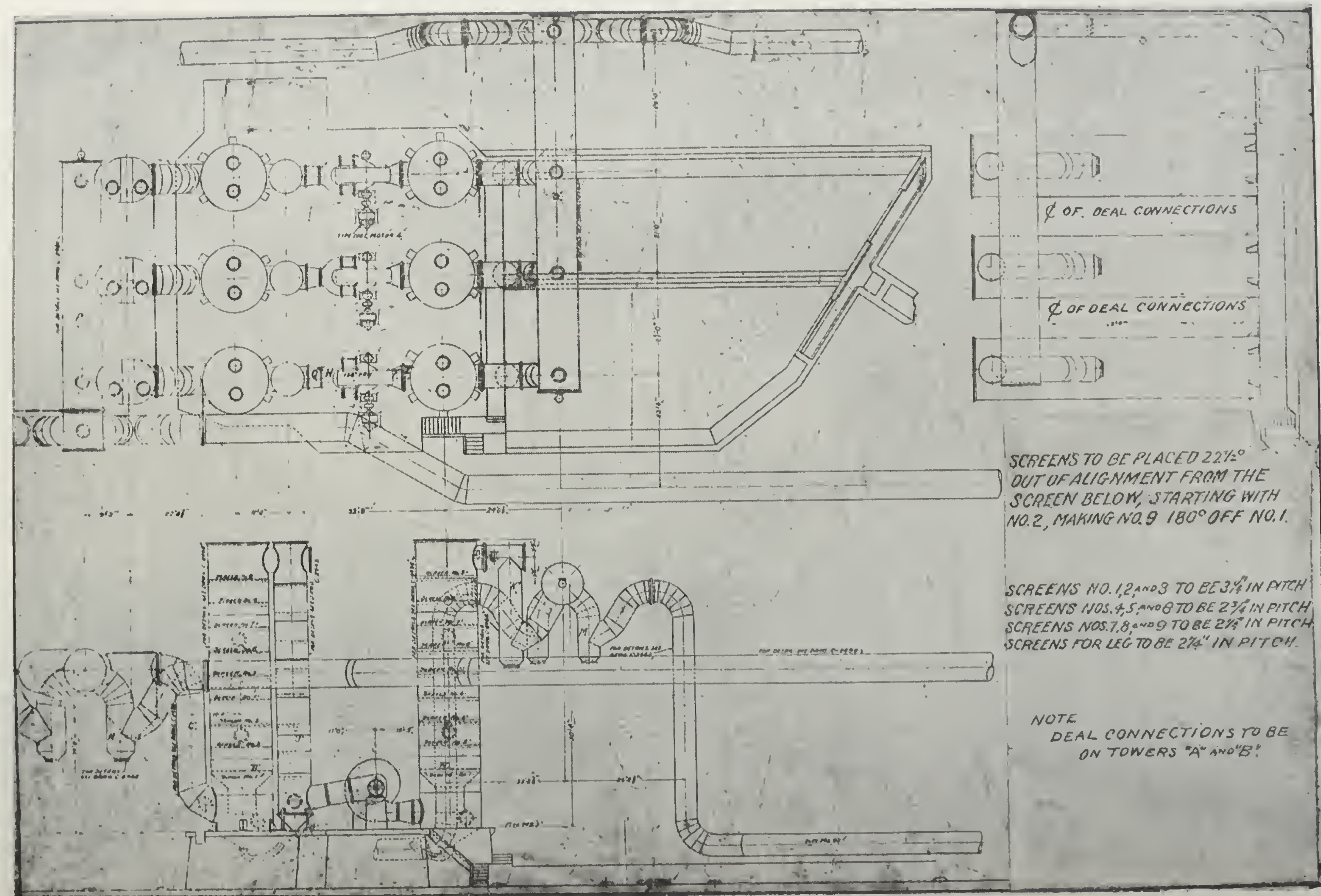

Fig. 2. Gas Cleaning Plant for Stoves.

A fan is very often placed in the line to boost the pressure if the plant is situated any distance from the furnace or stoves, or if the pressures carried in the plant gas lines are too low to return the gas from the washers to the stoves or boilers, etc. No water need be used on the fan and the current required is not expensive in a well designed installation; the operation of the plant, however, is so much more flexible that it is advisable to use it when conditions will allow, on account of its ability to temporarily change the delivery pressure when desirable.

While the apparatus described will bring the gas in condition to use under stoves and boilers, it must be further cleaned it if is to be used in gas engines. There are several very efficient kinds of apparatus now in use for this purpose. The principal of these are the well known Theisen washer, which is largely used for that purpose in this country, and the Schwartz-Beyer and Theisen Disintegrators that are largely used abroad; the two latter being improvements along the original Theisen principle. There last two mentioned types of apparatus are advocated for use in rough or primary cleaning, but so far none have been introduced into this country.

Figure 2 gives an idea of one of these modern primary gas washing installations in use at the Edgar Thomson Works of the Carnegie Steel Company for cleaning gas for blast furnace stoves.

REGENERATIVE STOVES

The use of clean gas on blast furnace stoves has made it possible to greatly increase their efficiency by attempting refinements in the stove construction, such as smaller checker openings and thinner checker walls, thereby obtaining increased heating surface. The design of gas burners is also being improved upon which still further helps to increase the efficiency of the stoves, as more perfect combustion is obtained. This part of the subject is only mentioned briefly, as it is more the details of construction we wish to consider.

There are many types of stoves, such as the two pass with center and side combustion chambers; three pass, and four pass. The design of each of these types varies greatly, some advantages and some disadvantages appearing in the design of each type.

It is important to study the most economical use of brick inside of a shell of given volume and to arrange the checkers, combustion chamber, gas burner, draught connections, etc., so that we get as perfect distribution as possible for the gas and air and also obtain the maximum capacity for the least expenditure. The problem, therefore, is to get as simple a stove as possible, having the required strength, with the greatest amount of well arranged heating surface, so that all the heat possible will be absorbed from the burnt gases in their passage through its checkers, and so that the heat will be readily given up in turn to the air in its passage through the stove.

A modern 500 ton furnace should have an equipment of four stoves of approximately 22 feet diameter, 100 feet high, each containing 60 000 square feet of heating surface. With this equipment there should be no difficulty in carrying a straight line heat of 1200 deg. Fahr., and still have plenty of reserve in case it is demanded by the furnace, and in addition the average stack temperature for such stoves should be comparatively low, not exceeding 400 deg.

Interesting experiments have been made with fire brick of the usual grade used in the construction of hot blast stoves to find the temperature at certain distances back from the face of the brick when exposed to a gas flame of approximately the same temperature as that obtained on the ordinary hot blast stoves, and then exposing it to air blast. These results briefly showed that with a temperature of approximately 2100 deg. Fahr. on the face, it took three hours for the temperature to rise to 1300 deg. two inches back from the face of the brick; also, when this face of the brick was exposed to cold air blast for one hour, the temperature two inches back from the face dropped to approximately 900 deg. This tends to prove that excepting for the need of structural strength it would be more economical to make the checker walls as thin as possible, and the checker openings small, so as to obtain the greatest heating surface, on account of the greater heating effect of the surface of the brick compared with the interior.

The maximum possible heating surface of a stove containing square checkers is obtained when the checker diameter and the thickness of the checker walls are equal.

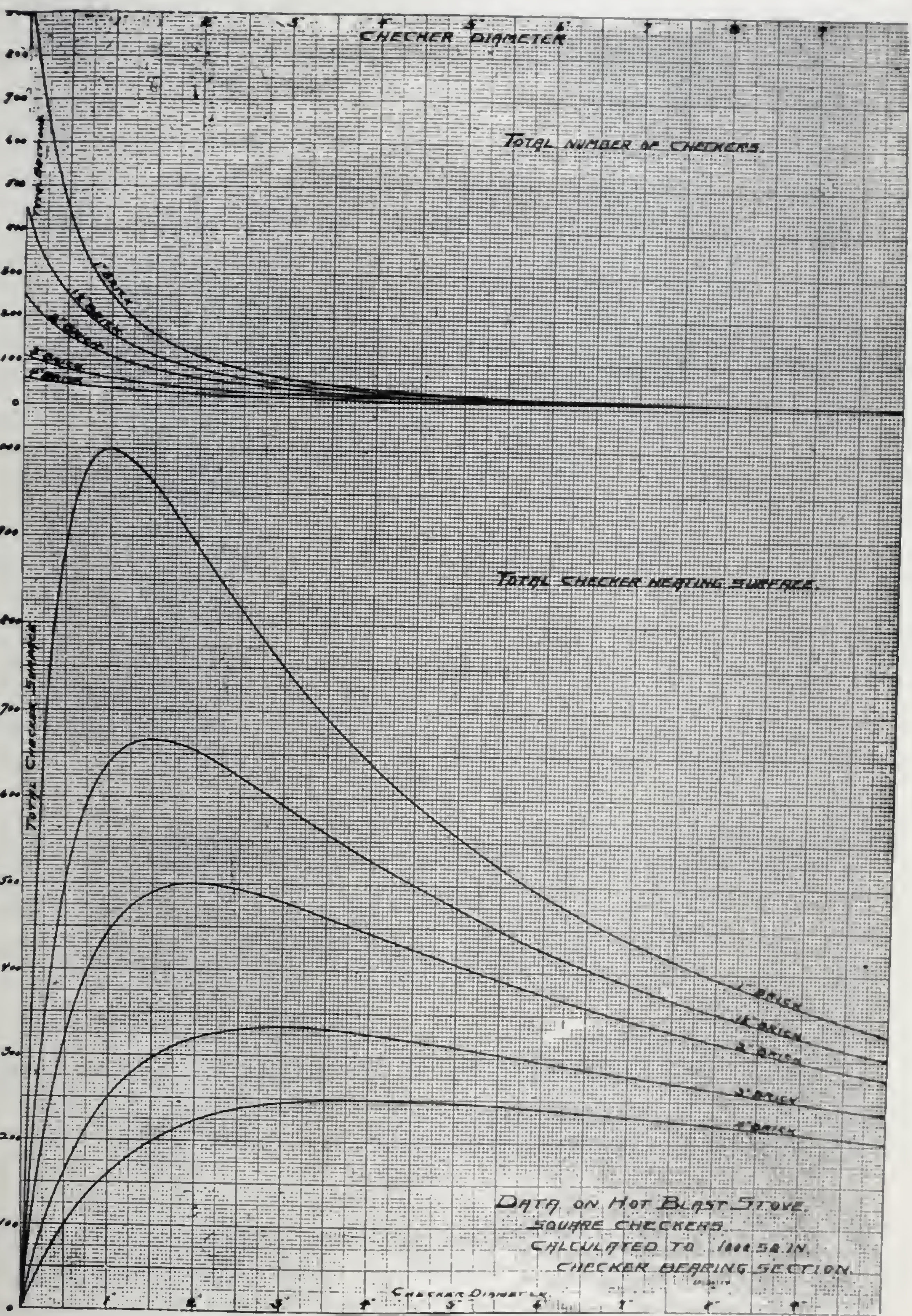

Fig. 3. Data on Hot Blast Stoves.

The maximum possible heating surface of a stove containing square checkers may be determined by dividing the product of the total checker area and its height by the thickness of the checker brick used.

Figure 3 gives some interesting curves prepared by Paul D. Wright, Assistant to Superintendent of Edgar Thomson Furnaces, which are very interesting in studying the relation between checker wall thickness and size of checker openings.

For comparison a checker bearing area of 1000 square inches and of unit depth is taken. The upper curves show the actual number of checkers using brick of varying thickness in checker work having various dimensions. The lower curves show the actual heating surface obtained per unit of height, corresponding to the brick thickness and checker dimensions as stated. On study of these curves it will be apparent that two checker diameters may be found which will correspond to the same total heating surface when built with the same size checker brick.

It can be seen from these curves that one inch openings with one inch walls will give three times as much heating surface per unit of volume as three inch openings with three inch walls.

This is of great assistance in studying the details of hot blast stove construction, as it enables us to determine the most economical use of brick work in the space inside of a stove shell and to obtain the greatest capacity of heating surface for the lowest cost.

It is important to place the bottom of a stove on a solid foundation. The shell should be of heavy steel plate, both horizontal and vertical seams double riveted, and of ample strength for the duty imposed upon it.

In choosing the diameter of stove there is less surface exposed to radiation in the larger diameter, but the checker pass on the larger diameter is subject to greater variation in gas distribution; also, there is more tendency for injury to the checkers by expansion and contraction with the large diameters. A 22 ft. diameter of stove has proved itself safe in this respect, and no trouble from crushing has been experienced from the

pressure of the brick with a stove of 100 feet in height. A fairly large combustion chamber is desirable in a stove of this size, as better burning of the gas is obtained. This area should not be less than 40 square feet. In some of the three pass and central combustion two pass stoves this area has been made too small and trouble was experienced in obtaining complete combustion of the gases before they reached the checkers, with consequent poor distribution of the products of combustion.

Regarding the size of checkers and thickness of checker walls, as mentioned before, structural considerations have to be followed rather than theoretical considerations of trying to obtain the greatest heating surface. However, the theoretical considerations are very useful as a guide. It does not look to be safe to use brick less than 2½ in. thick, or a smaller checker opening than 5 in., even with clean gas, on account of the importance of keeping these long passages clean and on account of the liability of expansion, breaking, or closing up of these long passages. Various standard shapes of checker brick are made that have proved themselves satisfactory by experience. In some cases corrugations are made in the brick with good results to obtain still greater heating surface. Great care should also be given to get the best distribution of gas and air under the checkers, so that there may be perfect freedom for the gas and air in their passage; in connection with the equalization of the draught, this is also an important consideration.

The type of gas burner to be used is also important, as the majority of gas burners used on stoves are very inefficient. With a better mixture of air and gas we can obtain a higher flame temperature and shorten the flame so as to confine it to the combustion chamber, so that nothing but the burnt gases reach the checkers. In many cases the gas is not completely burnt when it reaches the checkers.

In regard to the advantages of two pass and three pass stoves, there is a slight advantage in respect to the cubic feet of brick contained in a given space, and of square feet of heating surface per cubic foot of brick in favor of the two pass; also some practical working advantages on account of having the valves near the ground, together with the ease of cleaning.

There is no evidence that there is a better distribution of gas in one type of stove than in the other.

Two and three pass stoves are in most general use, as additional passes mean the loss of too much space by the additional partition walls required.

BLAST FURNACE POWER PLANTS

In modern blast furnace construction the tendency is for much greater concentration in power plants and the units preferred should necessarily be as large as practicable, as attention given to these considerations tends greatly to reduce fuel cost, operating expenses, and labor and material in repairs.

A modern 500 ton blast furnace requires approximately 2500 indicated horse power to operate it, of which 1800 indicated horse power is used on blowing engines, the balance for supply pumps, boiler feed pumps, condensers, hoists, unloading ore, pig machines, and other miscellaneous uses around a plant of this kind. It is important to produce this amount of power for as low a cost as possible and furnish as much power as possible for use outside the furnace plant. In this way a very important credit on the cost of producing iron is obtained.

In making a selection of reciprocating steam blowing engines, turbo-blowers, or gas blowing engines, as well as steam turbines or gas engines for power purposes, all the local conditions regarding the value of fuel must be thoroughly considered, as well as considerations as to whether or not there is a market for excess power. After this there should be no difficulty in arriving at a conclusion.

BOILER PLANTS IN CONNECTION WITH BLAST FURNACES

If boilers are to be used there should be a separate boiler house, and for large furnace plants it is preferable to have as few boiler houses as possible on account of more economical operating conditions. It is preferable not to have blast furnace boiler houses built as part of the power stations, on account of the dust, dirt, and gas usually around plants of this kind.

The boilers should be in large units, so as to keep to a minimum the number of units required for large powers, carrying at least 175 lb. steam pressure, and be equipped with all

modern economical appliances, such as superheaters, feed water heaters, plants for treating feed water, and economizers, etc. By securing the maximum concentration savings will be made on fuel, operating expense, etc., and the losses due to radiation, etc., will be lower and an average boiler efficiency of 70 percent should be easily maintained. A blast furnace boiler plant should be arranged so as to be gas or coal fired, and economical coal and ash handling machinery should be also installed. The boiler units should be so arranged as to have at least two passes, and so constructed that tubes can be easily kept clean, both externally and internally. This is accomplished more easily with straight, vertical tubes.

Similarly to hot blast stove practice much more attention is being given to burning the gas economically under blast furnace boilers by getting the best mixture of gas and air and the most economical combustion. Burners are being perfected to obtain the highest flame temperature, thus obtaining better heat transmission, better circulation, and lower stack temperatures.

DIFFERENT TYPES OF BLOWING EQUIPMENT

We have the choice of three different types of blowing engines, depending greatly on local conditions; namely, reciprocating steam blowing engines, turbo-blowers, and gas blowing engines. After determining the value of power for uses outside the blast furnace we should be in a much better position to make a decision.

From data available it looks as though we can expect 13 pounds of steam per horse power delivered from turbo-blower. The blower has approximately 70 percent efficiency. This gives approximately 18.6 lb. of steam per horse power for wind delivered to the main. Taking a modern reciprocating steam blowing engine at 17 pounds of steam, which is common practice, and 90 percent efficiency in the cylinders which is attainable with good clearance, low valve loss, slippage, etc., we would get 19 pounds of steam per horse power from wind delivered to the main. It therefore seems that while there is not very much gain in thermal efficiency to be expected with the turbo-blower over the steam blowing engine, there is a saving in space required, operating labor, oil, waste, packing, etc.

Many claims are made for the turbo-blower on account of its delivering a more uniform supply of air, effecting a lower coke consumption, greater production, etc. These claims look very questionable as it takes a definite amount of oxygen to consume a definite amount of carbon, no matter how it is supplied.

CHOICE BETWEEN GAS ENGINE AND STEAM EQUIPMENT

The blast furnace is a good gas producer and when properly cleaned this gas is an ideal fuel for high power gas engines. This fuel, as explained before, can be used for gas fired boilers and these in turn can supply power to steam turbines or reciprocating engines, pumps, etc. With the highest grade and most modern equipment of this kind we cannot look for much over 10 percent thermal efficiency; on the other hand if this gas is supplied to modern gas engines we can obtain 22 percent thermal efficiency. A gas engine plant is more expensive and costs more to operate. Therefore in making a choice of prime movers, this, together with the local conditions regarding the value of fuel and the field for excess power over plant requirements, must be thoroughly considered. Whatever choice is made in prime movers to attain the minimum operating cost, large units should be chosen, and the concentration of power generation, such as blowing equipment, electrical equipment, pumps, etc., should be carried out to as great an extent as possible. If possible all machinery of this kind should be in one large engine house. This is a very interesting subject, and much more thought is being given to these economies.

The advantages of a good reliable water supply is of great importance, as a modern furnace requires approximately 4 000 000 gallons of water per 24 hours. Also, additional water is required for gas washing, cooling, etc. High duty reciprocating pumps or motor or turbine driven centrifugal pumps are giving efficient results for this class of work.

Considering fuel costs, cost of installation, etc., the blast furnace gas engine would be the choice in most modern blast furnace installations, excepting where the value of fuel is very low, or where there is no outlet for excess power.

OTHER DETAILS RELATING TO BLAST FURNACE ACCESSORIES

There are many other details which I would like to discuss further, but in a paper of this kind it is impossible to do anything more than call them to your attention, as each detail is an important study in itself.

The arrangement of cast houses, so as to have iron runners as short as possible so as to reduce runner scrap is important. The use of large iron ladles of 35 tons or more capacity in transporting iron from furnace to mixer or pig machine has also in many places effected large savings in operating labor, labor and material in repairs, reduction of scrap, lining brick, etc.

The use of air dump cinder ladles is important if cinder has to be handled by this method. The aim should be for the commercializing of slag as much as possible, either by cement plants, cinder ballast plants, or other plants of a similar nature.

Modern machinery for unloading miscellaneous material, such as coke dust, loam, clay, etc., is an important detail. Modern methods of plugging the tapping hole and botting cinder notches with blast on furnace; the use of oxygen for opening hard holes,—all of these various details tend to economy in the use of materials, more regular working furnace, increased production, and lower coke consumption.

I have covered briefly some of the important details showing the trend in blast furnace construction. To reach the minimum cost of production is largely a matter of the quality and quantity of the product. In blast furnace practice they both go together; a regular working furnace will produce good tonnage of uniform quality. In addition to this the concentration of operating labor to as great an extent as possible also aids in reducing the cost of operation.

In closing it might be well to mention that all blast furnaces have individual peculiarities, and even after paying attention to as many details as possible often a great amount of study and thought is required to locate the cause of some of their short-comings.

A blast furnace manager requires a large amount of initiative to take advantage of all modern improvements that develop and to overcome and correct the many difficulties that are con-

tinually presented. He also requires an efficient organization where the aim is to improve the quality of product and reduce the cost of production to a minimum.

DISCUSSION

Mr. A. N. Diehl:* The trend of modern blast furnace construction is a decidedly intricate problem. In former times there was but one end in view, and that was the production of pig iron: First, of good quality; second, of large quantity; and third, as economically as possible.

Modern blast furnace trends, include several more heads. Under the one general head might be considered the production of slag for various purposes, such as: Cement making where granulated slag is required; ballast, when required, the slag is dumped hot and afterward reclaimed; and the manufacture into bricks with a further annealing.

Another general head is the more economical utilization of about 50 percent of the blast furnace energy, namely, the use of blast furnace gas in internal combustion engines. As a further example of these several conditions, it is quite a well known fact that blast furnaces are at this present time, being operated primarily for the purposes above mentioned, that is, where the principal reason for the operation of the blast furnace is due to the premier local demand for either pig iron, slag or gas. The two other elements, under these conditions, would then be by-products.

The commercial demands for these various products, and economical operation, are of course accountable for the above status. It is, therefore, as has been mentioned, a rather hard problem to determine just exactly what the trend of modern blast furnace practice is. The author of the paper has evidently assumed pig iron to be the main product and has briefly and accurately touched on the principal tendencies of modern practice.

The entire subject is so large that I wish to refer to, and enlarge on, only one paragraph, the one referring to Mechanical Charging Apparatus. Under this paragraph he divides the methods into two parts. The first, which is described as the

*Superintendent of Blast Furnaces, Duquesne Works, Carnegie Steel Company, Duquesne, Pa.

Neeland method, was the initial mechanical step after the various hand filling operations. This system was designed and applied to the Duquesne blast furnaces by Mr. M. A. Neeland, and consists of cylindrical detachable buckets having a bottom discharge, over a vertical moving bell which forms the base of the bucket. The bucket is carried by a stem which is attached by means of a hook to the trolley and is hoisted from the base of the furnace to the top where it is deposited on the gas seal and emptied by means of the vertical lowering of the bell in the bottom of the bucket, thereby allowing the material to flow directly and evenly from the base of the bucket onto the large bell. After the bucket is emptied the stem is drawn upward once more and then taken down the incline and deposited on a car beneath, and it is then ready for re-filling. Each charge, according to the original Neeland arrangement, consists of four buckets of coke and one of limestone, and another train consisting of three or four buckets of ore. When the buckets are emptied the train is moved so that the next bucket comes into position for hoisting.

All charging apparatus has three points in view: Distributing the material according to lumps and fines correctly in a receiving hopper; the disposition of the material properly on the large bell; and the proper distribution from the large bell into the furnace. I wish to consider only the first two points.

The principal idea of the management, in a hand filled furnace proposition was to see that the material was properly distributed on the main bell, and top fillers were carefully supervised. In most modern furnaces these top fillers have been supplanted by receiving hoppers, into which the ore is placed in such manner as to have it distributed on the main bell equally with regard to relative size.

As before mentioned the first step was to fill a receptacle at the bottom of a furnace, carrying the same to the top. The next step was the building of a receptacle on the top of the furnace into which the material was dumped from a skip, afterward being dumped to the main bell. Principally on account of unequal distribution of fines and coarse material, as well as the saving of time, the double skip was introduced whereby the

skips are dumped from opposite positions, thereby tending to make a more equal distribution in the receiving hopper or receptacle.

With the advent of the skip came the irregular cutting out of lining walls. This generally took place on the side where the gases could pass through the stock with the least resistance. The line of least resistance can be easily traced to a segregation of lumps on the side of the furnace which is caused by the constant dumping or tilting of the skips in the same direction. This dumping causes the fines to roll one way and the lumps another, each skip load having the same relation. The recognizance of this condition led to various experiments and apparatus to mitigate the irregularities of the tilting skip.

The simplest mechanical top in operation consists of a revolvable hopper, which is moved a certain number of degrees after each filling, in order to change the relative position of the segrated lumps in it. A number of furnaces are operating successfully with this improvement.

The same criticism, that of the coarse and fine material segregating, is equally applicable to the Neeland system, in which case the ore flowing from the bins into the buckets parallels the condition which prevails in the tilting skip to the receiving hopper.

I would therefore say that the receiving hopper on the top of a blast furnace filled by means of a skip corresponds exactly with a Neeland bucket filled from the bins on the bottom. In other words, the receiving hopper is a permanent bucket. The conditions favor the movable bucket in that it is leveled off on the bottom after filling and when centrally placed on the top, the ore falls evenly and equally on the main bell. This is impossible with receiving hopper, as the action of the skip is to pile the ore higher on one side than on the other, and it is not advisable to have men leveling it off on top of the furnace. This feature has been one of the most serious in tilting skip filling, and on account of its inaccessibility often leads to many difficulties which could be overcome if the work was done on the bottom.

Mechanical tops of various kinds have been suggested to obviate or minimize these difficulties, but most of them have

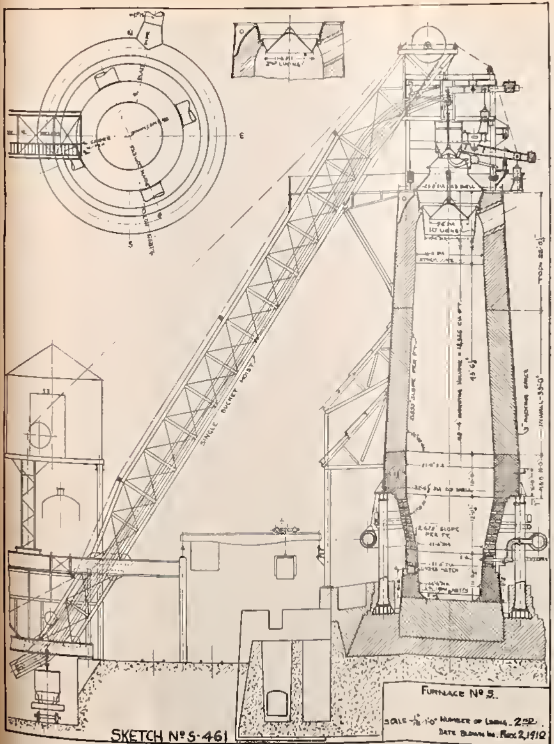

Fig. 4. Shows cross section of stock yard, granulating pits, and furnace with revolving, detachable buckets, at the base of the incline. A bucket is shown on top merely to indicate the position, and of course, would not be there in a single skip operation.

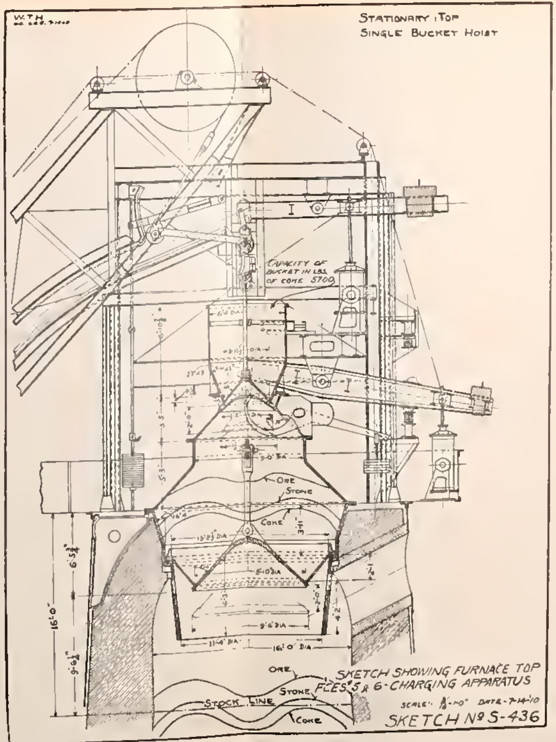

Fig. 5. Shows the bucket on top in position and illustrates the central distribution idea, the bucket being removed and the charge prepared and properly distributed in the stock yard before hoisting. It is clearly seen that the bucket and the receiving hopper serve identical purposes, with the advantage in favor of the bucket, as the work can all be performed at the base of the furnace.

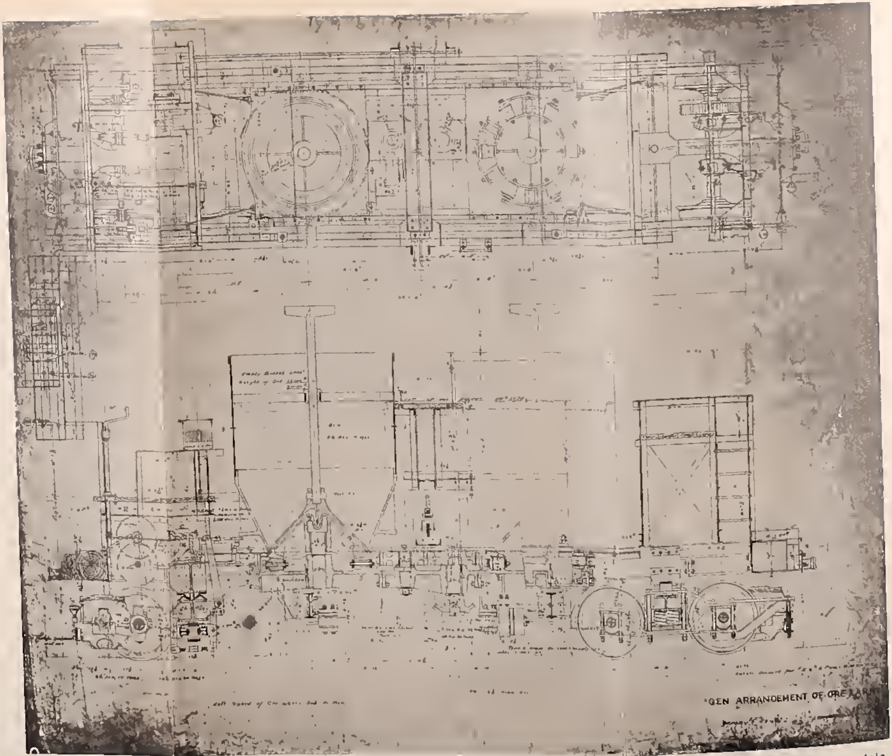

Fig. 6. Shows the ore larry with removable buckets, mounted on turn tables and revolving by means of a motor as the ore flows into them. This causes the bucket to be filled in alternate spiral layers of coarse and fine material as the buckets continuously revolve. When they are filled under these conditions it is evident that by emptying over the vertical dropping bell, forming the bottom of the bucket, an approximately perfect distribution of coarse and fines on the large bell is accomplished. The buckets can be revolved any number of degrees instead of continuously, if so desired. The entire bucket system is supported on the scale beam.

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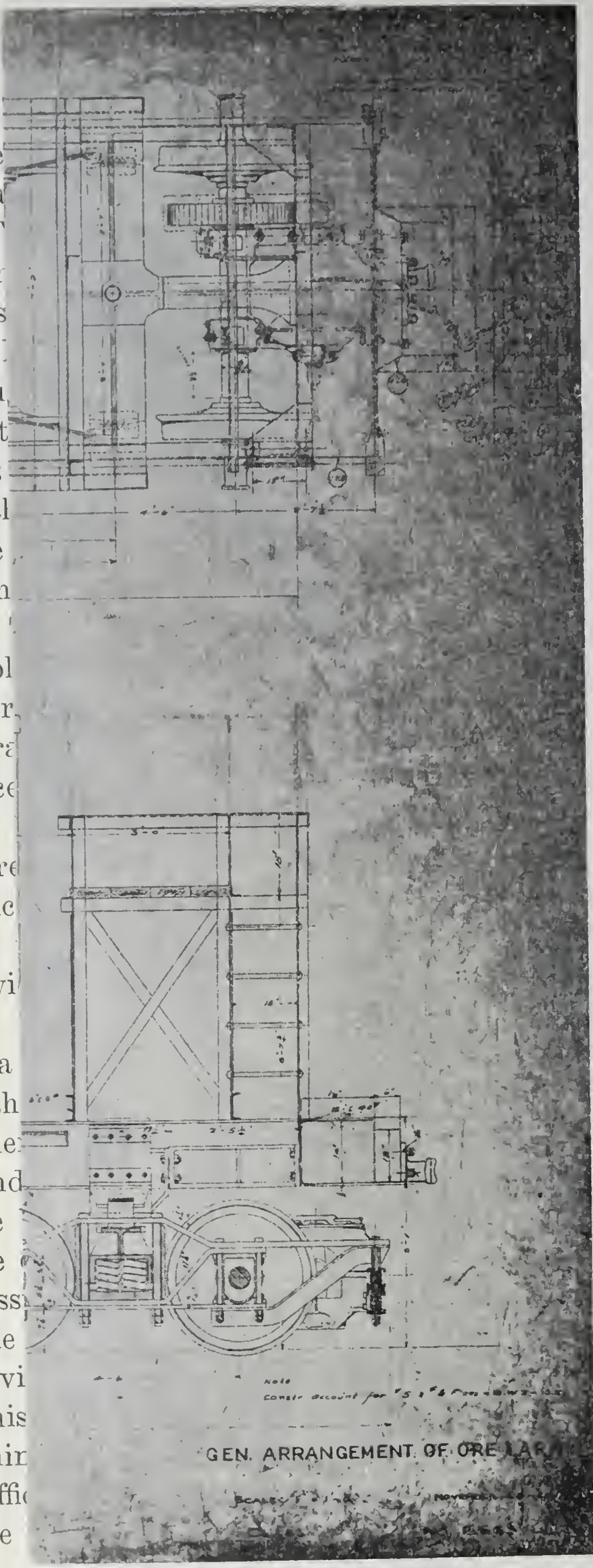

obvi by means of a motor as the ore flows into
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fallen by the wayside due to the difficulty of operation and up-keep.

The difficulty of ore segregation in the buckets and receiving hoppers, together with the view of avoiding complicated revolving tops, led to the principle of preparing each charge on the bottom by continuously revolving the buckets while the ore is flowing into them at the rate of about 30 revolutions per minute. The result of this continuous revolution destroys all chances of the ore segregating vertically and instead forms a spiral stratafication of coarse and fines. When a bucket filled in this way is carried to the top and dropped vertically, it is evident that the proportion of fine material on any segment of the bell will be equal. It is evident that the more revolutions the bucket makes the nearer will be the proportions of coarse and fine material in each vertical plane passed through the center of the bucket.

Various model tests show this very closely. A glass model bucket was so arranged as to revolve and ore of different sizing was allowed to flow from a bin into it. After the bucket was filled the contents was divided and each division sieved separately over different mesh screens, to determine the relation of the ore in the different divisions. Below is a result of these tests:

ORE DISTRIBUTION TESTS

(July 25, 1907.)

Total weight of sample 97½ oz.			Total weight of sample 133 oz.		
Division A Wt. 51½ oz.		Division B Wt. 46 oz.	Division A Wt. 69.5 oz.		Division B Wt. 63.5 oz.
9.0 oz.	On No. 8 screen	8.5 oz.	4.0 oz.	On No. 8 screen	3.5 oz.
19.0 "	20 "	14.5 "	19.0 "	20 "	16.0 "
16.0 "	60 "	15.5 "	28.0 "	60 "	26.0 "
7.5 "	Thru 60 "	8.0 "	18.5 "	Thru 60 "	17.5 "

Assuming each division to contain equal amounts before by weight, and multiplying division "B" by the ratio of the total weight of division "A" to division "B", the following relation is shown:

9.0 oz.	On No. 8 screen	9.52 oz.	4.0 oz.	On No. 8 screen	3.83 oz.
19.0 "	20 "	16.20 "	19.0 "	20 "	19.70 "
16.0 "	60 "	17.30 "	28.0 "	60 "	28.40 "
7.5 "	Thru 60 "	8.96 "	18.5 "	Thru 60 "	17.50 "

The results of the tests show a very close approximation of the same sizing in each division, and it would naturally follow

that if the ore were subdivided properly, and centrally discharged from a bottom discharge bucket onto a centrally discharging main bell, that the material should arrive in this condition in the top of the furnace. The glass model showed further that, when the glass bucket was full, each revolution was distinguishable and could be counted by the alternate layers of coarse and fine material, an additional indication that the distribution was being effected as contemplated. It would seem that the above method of operation should give as near perfect a distribution as could be arrived at from the standpoint of equally distributing the coarse and fine material in the burden.

A number of modified installations using the same main principle of preparing the charge at the bottom, are in operation in this country, some of which have buckets permanantly attached to the hoist and revolve continuously, or a certain number of degrees, while being filled or before hoisting. The material is collected by larry cars and slowly dumped into the attached bottom dumping buckets. Reports from Germany, France and England also indicate that this system is being used on most of their newer installations.

The key-note of all filling, as before mentioned, is the proper placing of the material in the buckets or receiving hoppers, and it is the desire of this paper to point out a comparison of the two general systems, which with modifications, are used in 95 percent of the modern operating blast furnaces, also to draw out the advantages of preparing the charges properly at the bottom where this work should be done. The preparation can be done there with ease and safety, under the proper direction and supervision, rather than on top with all the difficulties and dangers attending work at that point.

Mr. George W. Vreeland:* Mr. Maccoun has brought out many good points, which I will not attempt to discuss, as he has covered this subject in a highly satisfactory manner. I will only attempt to elaborate on a few of those points, and in a general way show some of the advantages of the present day tendency in the construction of a blast furnace.

That the large amount of thorough experimenting and

*Superintendent of Blast Furnaces, Mingo Works, Carnegie Steel Company, Mingo Junction, Ohio.

scientific research invested in the blast furnace and its many accessories is responsible for the blast furnace as it stands today, and the still better furnace of the morrow, must be conceded when we review the raw material conditions of a few years ago and the present time.

Only a few years ago, we used ores that averaged a metallic yield of 60 to 61 percent, with an average of 5.70 percent silica. At that time 35 percent Mesaba ore in the burden was considered high. This material necessitated about 700 lb. of cinder to carry off the gangue contained in the materials required for one ton of iron. The coke was made from the best Connellsville coal.

At the present time the ores average from 48 to 54 percent metallic yield, with an average silica content of 8 percent, and we are now using from 75 to 95 percent Mesaba ore. Owing to the increased impurities in the ores and coke we are now forced to carry from 1050 to 1400 lb. of cinder per ton of iron. The importance of this factor may readily be seen when we consider that this is from 50 to 100 percent greater than it was when we were carrying the former burdens. This, of course, appreciably lowered the efficiency of the furnace as an iron producer. I will not go into the inferior physical conditions of the ore burdens, due to the increased percentage of Mesaba, at this time, as this has already been the subject of many papers, but this, too, has contributed, to a great extent, to the problems of the blast furnace manager.

Notwithstanding these disadvantages, which can only be appreciated to their proper degree by those who are familiar with the handling of blast furnaces, we find, today, that our tonnages are just as high, coke per ton of iron a little lower, and product of just as good quality.

The success of the present day blast furnace manager, in equalling, if not surpassing the records of the past, under the inferior materials condition, has only been brought about by diligent study, and the closest observation, as regards not only the blast furnaces and their equipment, but also of methods and organization.

In our designing of the blast furnace, we must not lose sight of the fact that long life of the furnace is one of the

greatest economical factors in the production of pig iron, as with a short lived furnace we not only have a small tonnage on the lining, but the iron produced is very irregular in quality, daily tonnage low, and coke higher; whereas we find that a long lived furnace is more efficient in every direction.

This factor not only applies to the furnace proper, but also to its equipment, and when designing, provision must be made for the changing or repairing of any part which fails, with the minimum amount of lost time. If this is kept in mind, delays will be avoided, and we will be handsomely repaid for the care and consideration given to the designing and construction.

THE FURNACE TOP

I will first consider the furnace top, for the reason that I think this is one of the most vital parts of the blast furnace. This part has come in for a large amount of attention, and justly so, since with a poorly designed top, consisting of bad arrangement of charging equipment and gas offtakes, we cannot look for maximum economy in operation.

I believe that more inferior operating can be attributed to faulty design and construction of the top than to all the rest of the equipment combined, as the effects of irregular distribution are far reaching and, in a very short period, may, and in fact, have been known to damage a furnace so that economical operation was entirely out of the question, for not only was it impossible to produce iron at a reasonable cost, but the iron produced was very irregular in quality, and so bad at times that it could not be used in the manufacture of steel without mixing with a better quality iron.

A condition of this kind very often lowers the efficiency of other furnaces, especially when there is only one other furnace running, since we must always run this other furnace hot in order to take care of the inferior produce of the troublesome furnace.

Sometimes this condition can be remedied, to some extent, by changing the size of the bells, and adjusting same, but ofttimes the trouble is far deeper seated: Very often the damage done to the lining of the furnace by improper design of the

top is such that a new stack lining is necessary, and this in a very short time; often a bosh has been torn out, bearing proof that the faulty design of the top, consisting of the two factors aforementioned, had been the cause of the trouble. Of course the renewal of the lining did not eliminate the trouble, the top had to be changed somewhat before satisfactory operating conditions could be obtained.

At the present time, it is the opinion of a number of blast furnace managers that the dome type of top is the better design. The shell of the furnace, in this design, is drawn in at the top, and a heavy steel ring riveted to the inside, on which the hopper is seated. Such an installation gives excellent results over the old design, consisting of a straight top, with brackets from 4 to 5 feet long riveted to the inside of the shell, on which to seat the hopper. On the dome type top floor plates are eliminated, and a tight top is obtained.

I will attempt to give the advantages derived from a dome top over the straight top type:

With the dome type, we can take the gas off at the high point of the furnace, and four uptakes are invariably employed, since the chief reason for adopting this type is that that number of off-takes can be used without interfering with, or in any way, lessening the strength of the top, in fact, there is less weight on the top of the furnace when this top is used, than there is when the other type is in use.

These four uptakes are highly desirable, as the amount of flue dust is reduced to a minimum, providing these offtakes are equidistant, and that they are of large enough dimensions to reduce the velocity of the gas to 2000 or 2200 ft. per min., and that the downcomers are proportioned to take care of that velocity.

With the gas taken off from the four points as described, we can reasonably expect a more uniform condition at the tuyeres, resulting in a more uniform product; this of course, being the development of the more regular descent of the raw materials, due to the better distribution of the ascending gases.

These desirable results we can scarcely expect from a furnace with the straight type top, especially when equipped

with the offtakes on one side, and this type of top is responsible for the following operating condition.

The ore is better prepared in the side from which the gas is taken off, thereby causing the furnace to work better on that side, than on the other; this leads to a channelling of the gases, resulting in rolling, high flue dust production, high coke, irregular product, and general unsatisfactory conditions, with one possible remedy, i. e. equalize the offtakes.

As previously stated, the flue dust production is decreased somewhat, due to the gas being taken off at the four uptakes, as the particles of material, in falling from the bell, drop into what we may term the "zone of minimum gas velocity", and must make a complete reversal in direction to go out of the uptakes; whereas, in the furnace with the side offtakes, the material is precipitated into the "zone of maximum gas velocity", and only a change in direction of 90 deg. is necessary to pass it through the offtakes and into the downcomer.

This may be better understood when I say, that on most furnaces equipped with the side offtakes, the maximum velocity of the gas is below the bell, and through which the stream of raw material must pass, while in the dome top, with vertical uptakes, the maximum velocity of the gas is probably 4 feet above the bell; so of course the material does not have to pass through the current of gas when it is at its greatest velocity.

The relative values of a stationary and a rotary top, I will not attempt to discuss here, but many a poor working furnace, equipped with a stationary top, and with a distinct separation of the lumps and fines in its distribution, has been greatly benefited by the installation of one of the better type rotating tops.

We can attribute the excellent work of many of the stationary top furnaces to a careful adjustment of the following points: Skip speed; angle of dump; shape of receiving hopper; location of skip, when dumping, with regard to the center line of the furnace; the shape and size of skip car, and method of filling same.

Any one of these may cause an irregularity that will prove very troublesome, but should be corrected, even though the cost may be considerable.

THE BLAST FURNACE BOSH

The bosh construction of a blast furnace should be amply strong; bands between each row of cooling plates, are considered, at the present time, to furnish the necessary strength. These bands are from 1¼ in. to 1¾ in. thick, and are supported by substantial castings, either of iron or steel. These castings prevent a possible slipping down of the band, and also facilitate the construction of the bosh.

At least one row of plates should be placed below the tuyeres, to take care of the cutting action of the blast at that point.

The hearth jacket has been described by Mr. Maccoun. If it is amply strong, the brickwork can be laid up against it, with practically no expansion space. My practice is to lay the brick ⅜ in. from the jacket, and grout the space with clay.

This method will prevent cracks, and break-outs which result from cracks; as a large percentage of the break-outs in the hearth are due to cracks in the brickwork.

High grade brick, the best of workmanship, and a well designed jacket of cast iron, 5 to 6 in. thick, with links and bands, or a heavy riveted steel plate jacket, cooled inside with cast iron water cooled staves, or outside with sprays give excellent results.

Mr. Maccoun has handled his subject in a very creditable manner, and I would find great difficulty in adding to what he has already said on the other parts of the furnace and equipment, but I will now state in what direction our efforts are being put forth to secure further economy and regularity in the operations of the blast furnace.

The modern blast furnace should be equipped with suitable gas scrubbers, to put the gas in a suitable condition for economical combustion in the stoves and boilers.

With clean gas, a scientifically designed burner, and the gas under constant pressure, there is no reason why we should not approach theoretical conditions. With dirty gas of varying pressure, our present day burners set for ideal conditions at one pressure would be away off as soon as that pressure changed, demanding either more or less air; for this reason we should have the gas as near constant pressure as possible, either by regulating fans, or burners, or both.

A burner, on both stoves and boilers, so designed that the gas velocity will determine the quantity of air drawn in, and thereby maintain perfect combustion of the gas at the various burner openings, is a problem which we hope to solve some time.

A further possibility in this line of the furnace equipment is the pre-heating of the air used for combustion. This we hope to accomplish by means of the heat of the waste gases. The theoretical figures look very promising; of course the air must be used under pressure, say of about 2 in. water, to force it through the heating coils, which will be situated in the waste gas ducts leading to the stove or boiler stacks.

Using warm air of 350 to 400 deg. Fahr. our combustion temperature would be raised considerably, this being the resultant of the initial temperature of the gas and air, and the combustion temperature of the combination.

This will enable us to carry higher heats with the same quantity of gas consumed, or the same heat with a lower combustion.

The cleaning of the gas is essential to high flame temperature as the intense combustion temperature of the gas low down in the stove, will cause the brick to combine with the ore dust, forming a fusible cinder, and destroying the combustion chamber walls.

In the search for efficiency the quantity of air blown into the furnace is being investigated, and attempts are being made to regulate this, also to correct for temperature. Some form of meter can be used in the cold air main, and I have no doubt that this would develop into a more uniform weight of oxygen being supplied to the furnace, and eliminate the uncertain engine losses.

Some operators, are, to a small extent, correcting the volume of air for atmospheric temperature, with encouraging results. It seems the more rational way, as we should be more desirous of knowing the weight of air to produce a certain result in a furnace, rather than the volume, as that is only an approximate figure, unless the temperature is given.

With a more uniform weight of oxygen supplied to the

furnace, a more uniform quantity and quality of iron would be produced, of course, accompanied by economy.

The Rotary Kiln, Dwight Lloyd, and Greenwaldt methods of treating flue dust all produce a very desirable material, without adding any foreign matter, which would reduce the iron content of the product, and require coke and limestone to eliminate it. This porous product tends to open up the dense Mesaba ore burden, thereby giving a smoother running furnace, with less flue dust loss.

As a summary, all our efforts are being put forth to build a blast furnace plant, with "Safety" always in view; strong so that delays and breakdowns will be reduced to a minimum, with all possible labor saving devices, and the reduction of all raw material losses to a minimum, as it is there where our big savings must come in the future.

These results can only be obtained by careful consideration of the plant as a whole, and also of all the details of construction.

The raw materials are becoming slightly inferior year after year, and it behooves us to look for economy and efficiency in every direction, in order to keep up to the standard established in the past.

Mr. J. M. Camp*: I would like to have the speaker describe the electrically operated top he mentioned.

Prof. W. Trinks†: I am not a blast furnace man and I am hardly qualified to speak. However, I have been wondering while listening to this paper whether the dry blast which caused so much stir at one time is dead and forgotten now.

Furthermore, I wondered about the terms,—two pass stoves and three pass stoves. From the perusal of *Stahl und Eisen* I noticed that all German stoves are really one pass stoves, that is to say, there is a lateral combustion shaft and a downward checker pass and since the checkers are the only things that count, it is a one pass stove.

This type of stove has always appeared right to me from

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a theoretical point of view, because hot gases going down, tend to equalize the flow whereas hot gases going up tend to make flow more uneven. It has been said that hot gases going down "hunt a cold hole."

What I have said may be all theory, but if it is wrong, there are enough blast furnace men here tonight to set me right.

MR. L. E. RIDDLE*: As Professor Trinks has asked for some information in regard to dry blast and as I operate the Isabella Furnace dry blast plant, which was the first installation and having been with it from the beginning, I wish to say: While some of the claims made on the basis of the early work are larger than those we make now, we are still firm in our belief, that with modern dry blast equipment which will hold the moisture in the blast below two grains per cubic foot, we can make an increase in output of from 8 to 12 percent with a 10 percent saving in coke.

We have made a number of experiments at Isabella Furnaces, changing the furnaces from natural air to dry blast and vice versa, and believe the claims have been proved correct.

In line with modern blast furnace construction I wish to say a few words on thin lined furnaces. We operated the first one built in this country at the Lucy Furnace plant and later on built one at the Isabella Furnaces. Some of our best practice has been made on these furnaces, smooth working with low fuel consumption, but our work verifies Mr. Maccoun's statement: That after the brick is partially lost the coke per ton runs up.

We have found thin lined furnaces very satisfactory especially in making special irons, such as Ferro Manganese, Spiegeliesen, etc., and we have had better success with the products of thin lined than in thick lined furnaces as we can operate longer without relining.

THE AUTHOR: Mr. Diehl's interesting description of the Neeland type of top, etc., and its modifications, I am sure was of great interest to all of us, and it adds a great deal to my paper. Mr. Vreeland's details of the various types of furnace tops are also of great interest, as are also further remarks on the economical use of blast furnace gas. He also mentioned a

*General Superintendent, Isabella Furnaces, Carnegie Steel Company, Pittsburgh.

meter in the cold blast main. The General Electric Company have a meter of that kind that looks as if it might be of great assistance to us. This meter will be tried at our plants in the near future. Mr. Riddle has answered Mr. Trink's question to a great extent on dry blast; I do not think dry blast is dead by any means. The only thing is that in many of our plants we are deficient in not having enough stove capacity and other improvements. The tendency is and has been to get these deficiencies overcome first and later on we think we can still obtain 10 percent increased production and 10 percent less coke consumption by using dry blast. Regarding Mr. Trinks' question about the German one pass stove, I am not quite sure what he means by that. I think he means the two pass stove. As I understand it the two pass stove is the stove that is usually used in Germany, and it is also used to a great extent in this country. The two pass stove has a combustion chamber in which the gases rise and then come down through one checker pass, as Mr. Trinks described.

It is a one checker pass. That is what he means when he says a one pass stove; but we always call it a two pass stove in this country. It is a very excellent stove and it is preferred by a very great many blast furnace operators to the three or the four pass stove. Of course there is some advantage to each of the other types of stove, but I think on the whole we have installed more two pass stoves than three pass stoves.

Regarding Mr. Camp's question about how this electrically operated top works, I see he has left but I will try to describe it. The only feature of the top that works electrically is the bells and skip hoist. By operating the bells electrically we avoid condensation losses of steam, and the power required to operate them in a year's run is much less than with the steam, air or oil operated bells. This results in quite a saving by the use of the electrically operated bells which, figured for a single blast furnace amounts to a saving of approximately $2000 a year on fuel over steam or air operation. These tops are being operated quite successfully in many blast furnace plants.

Mr. N. F. Foner*: The speaker has elaborately covered the subject of the "Trend of Modern Blast Furnace Construc-

*Designing Draftsman, Edgar Thomson Works, Carnegie Steel Company.

tion" without, however, mentioning the importance of the utilization of flue dust and waste heat. Perhaps he has purposely omitted these features since either of the above mentioned subjects would make a very good evening's discussion.

I do, however, consider it rather necessary to mention them in connection with the Trend of Modern Blast Furnace Construction, since the degree of utilization of flue dust and waste heat will prove to be two important factors and by themselves will certainly affect the economical operation of the blast furnace.

Considering that the downcomers and dust catchers, as well as the gas washers, are necessary equipment for the blast furnace, not only for their respective operation, but also to make the places tenable for the employes, the expense of the equipment must necessarily be charged to the blast furnace and, considering that for the continuous operation of the furnace we are also compelled to remove the dust from the dust legs to the dust pile, we get this valuable by-product, theoretically speaking, free of charge.

Considering further that this flue dust contains some 60 to 70 percent of iron (mostly magnetic) which is or can be utilized at the blast or open hearth furnaces, my contention is obvious.

It requires, of course, the expenditure of a special plant with a number of various machines, mostly patented devices, as well as a few small special type furnaces.

As very few firms are using the same or similar equipments I believe a paper on the description of the so-called flue dust plants would prove of interest to every blast furnace man.

Further, as the conditions of the waste heat are similar, i. e., each heat unit that is utilized before it passes the stack means an equivalent gain for the furnace, although not necessarily used at the furnace proper, without any additional expense, except for the equipment. I am well aware of the various types and applications of boilers, superheaters and economizers for this purpose, but it seems we have not yet attained the practical limit and a comparison of data of various equipment will deserve the attention not only of the steam engineer but also that of the blast furnace man.

TOWER FOUNDATIONS FOR THE CRISTOBAL-BALBOA TRANSMISSION LINE

By Ira W. Dye*

A description of the foundations of the Cristobal-Balboa Transmission Line requires a brief summary of the entire system of generation and distribution of power for the Panama Canal, of which the Transmission Line is a part.

Power is generated at a hydro-electric plant just below the spillway of Gatun Lake, by three 2666 K.V.A., 3-phase, 25-cycle, 2200-volt generators, each driven by a vertical turbine of the Francis type, using water from Gatun Lake. The current is delivered at 2200 volts to a sub-station east of Gatun Locks by lead covered cables in duplicate vitrified clay, 20-way duct lines on the downstream slope of Gatun Dam, crossing the locks through a tunnel under the floor. Suitable transformers, switches and protective devices deliver the current to the transmission line at 44 000 volts. The transmission line follows the line of the Panama Railroad from Cristobal, the Atlantic port, to Balboa, on the Pacific, a distance of 47 miles. Sub-stations are provided at Cristobal, Gatun, Miraflores, and Balboa, and all are of similar type, except that provision is made at Gatun for feeding the transmission line from the hydro-electric plant or from a steam plant used during canal construction, and for taking current from the line or direct from the generating plant to operate the locks, and a similar provision is made at Miraflores for making use of an existing steam plant or drawing power from the transmission line. The sub-stations at the termini are step-down transformer stations to deliver power to the shops, docks, and coal handling plants.

The transmission line follows the right-of-way of the Panama Railroad throughout its length, this being the only

Contributed to the Proceedings by a non-resident member.

*General Foreman, Transmission Line, Isthmian Canal Commission, Culebra, Canal Zone.

feasible way of crossing the Isthmus, except the Canal itself. The various wide and deep arms of the Gatun Lake, and the almost impenetrable jungle on all sides, preclude the use of any other route. The advantages of easy maintenance, facility of future electrification of the railroad and the fact that all settlements and all canal works are reached by the railroad also indicate this as the proper route for the transmission line.

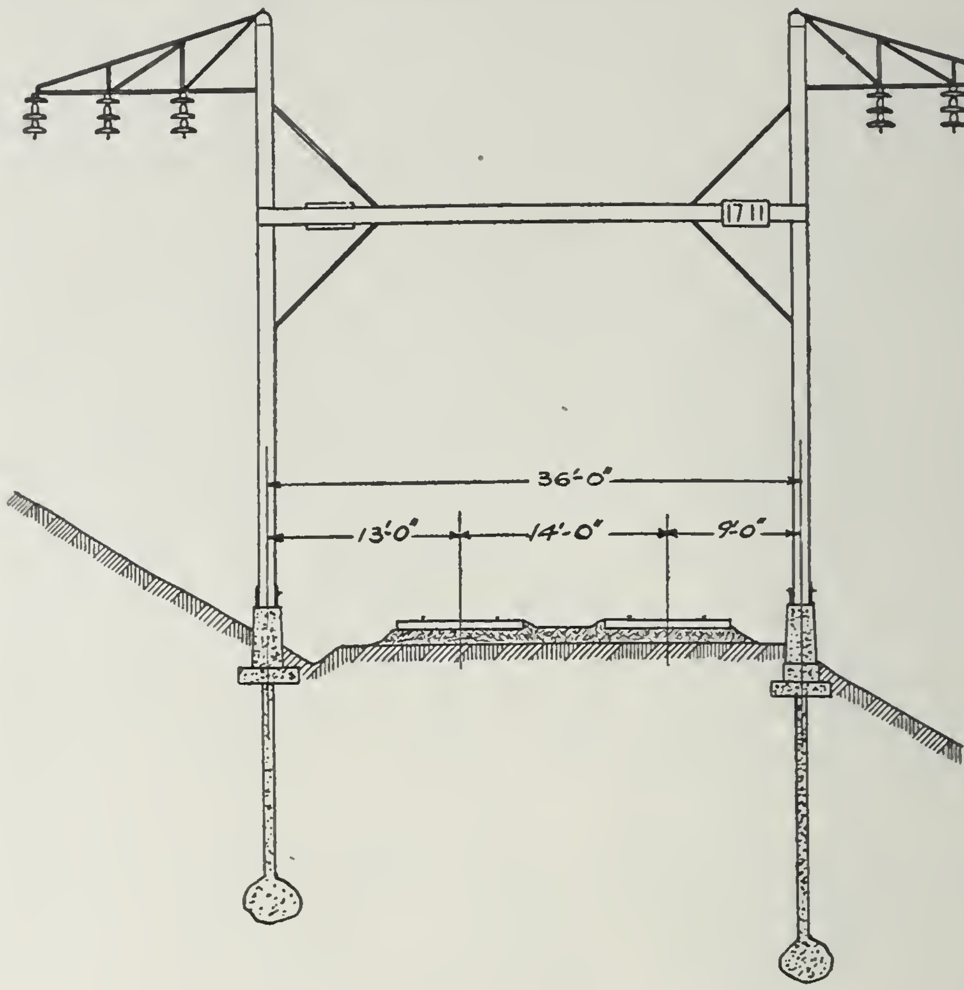

Fig. 1. Track Span Bridge.

The supporting structure for the wires is a track span bridge consisting of an *A* frame on each side of the track with a heavily braced cross bridge, the wires carried by suspension insulators from cantilever brackets outside the *A* frames. The line is in duplicate throughout, the power wires hanging in a horizontal plane on each side of the track, and the ground wires carried on top of the *A* frames. The phase wires are seven strand, *2/0* hard drawn copper, spaced five feet from each other and from the steel structure, and the ground wire is a $\frac{5}{16}$ in. copper clad wire, connected at every bridge by a wire down one leg of the *A* frame to a ground plate embedded in moist earth. These features are indicated in Fig. 1, and the photographs.

The foundations are subject to some rather difficult conditions of design. The Panama Railroad, as relocated outside of the Canal prism, abounds in curves, which introduce angle towers as a usual, rather than special, condition. Clearness of vision for engine drivers demands a wide bridge, and 36 ft. is the standard adopted. This locates the foundations on the slope of the fills or cuts, and it was impossible to excavate pits large enough to build a gravity type of anchor without undermining the track and endangering traffic. The type adopted is shown

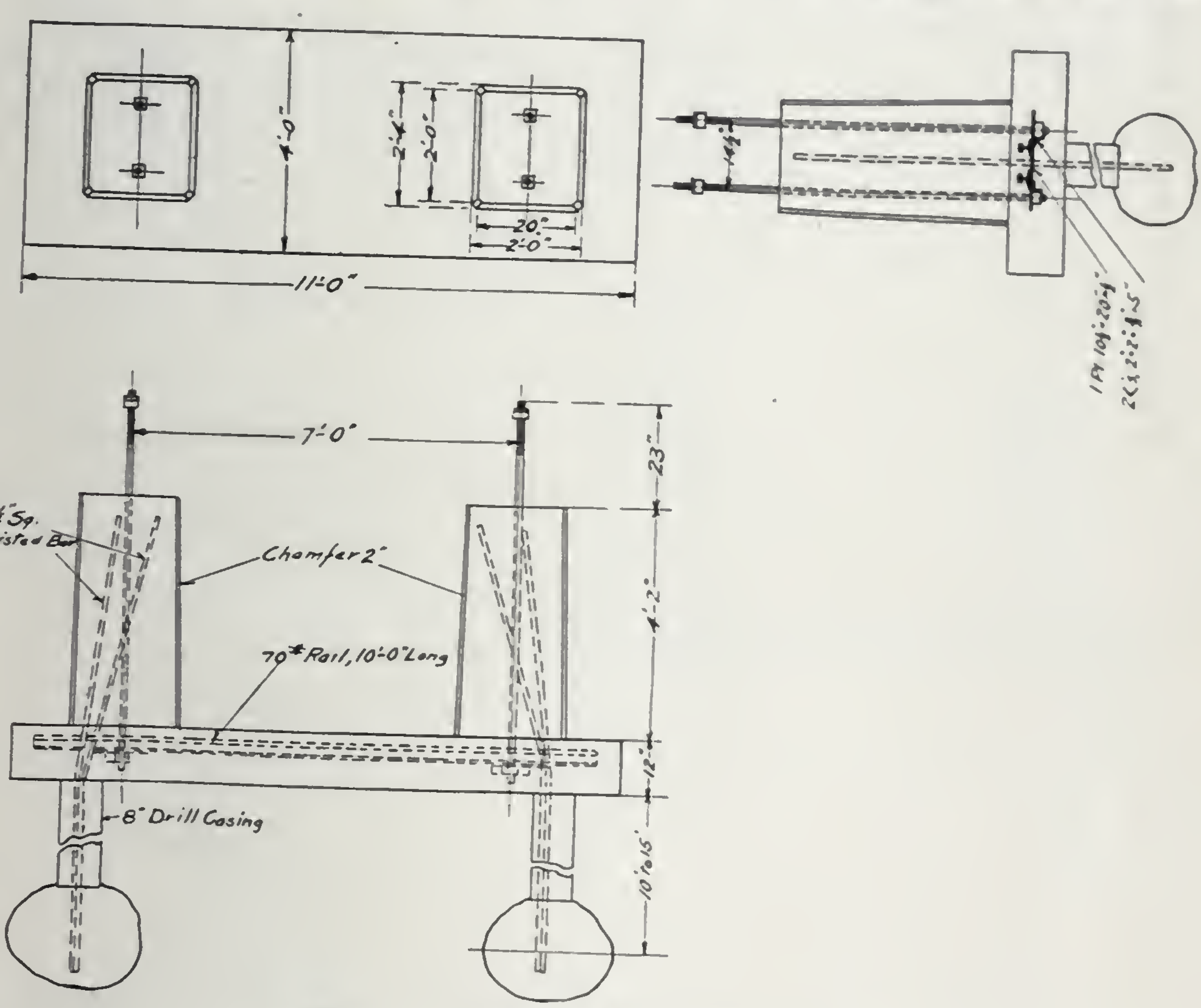

Fig. 2. Typical Foundation.

in Fig. 2 and consists of a sub-base one foot thick surmounted by two pedestals 4 ft. 2 in. high, anchored by a pile under each pedestal, formed by drilling and casing an 8-in. diameter hole, expanding the bottom with dynamite, and filling with concrete, reinforced, for tension only, against the uplifting effect of the overturning moment on the tower. Varying conditions along the right-of-way caused numerous modifications of the type, but the essential features are retained in all cases.

As may be noted in Fig. 2, the anchor bolts extend the

entire depth of the pedestals, and are anchored to two 70-lb. rails by a plate, the lower nut of the bolts being below, and the rails above, the plate. The rails are embedded in the sub-base, and the reinforcing rods from the anchors extend through the sub-base almost to the top of the pedestals, tension on the anchor bolts being transmitted by the bond of the steel to the expanded anchors.

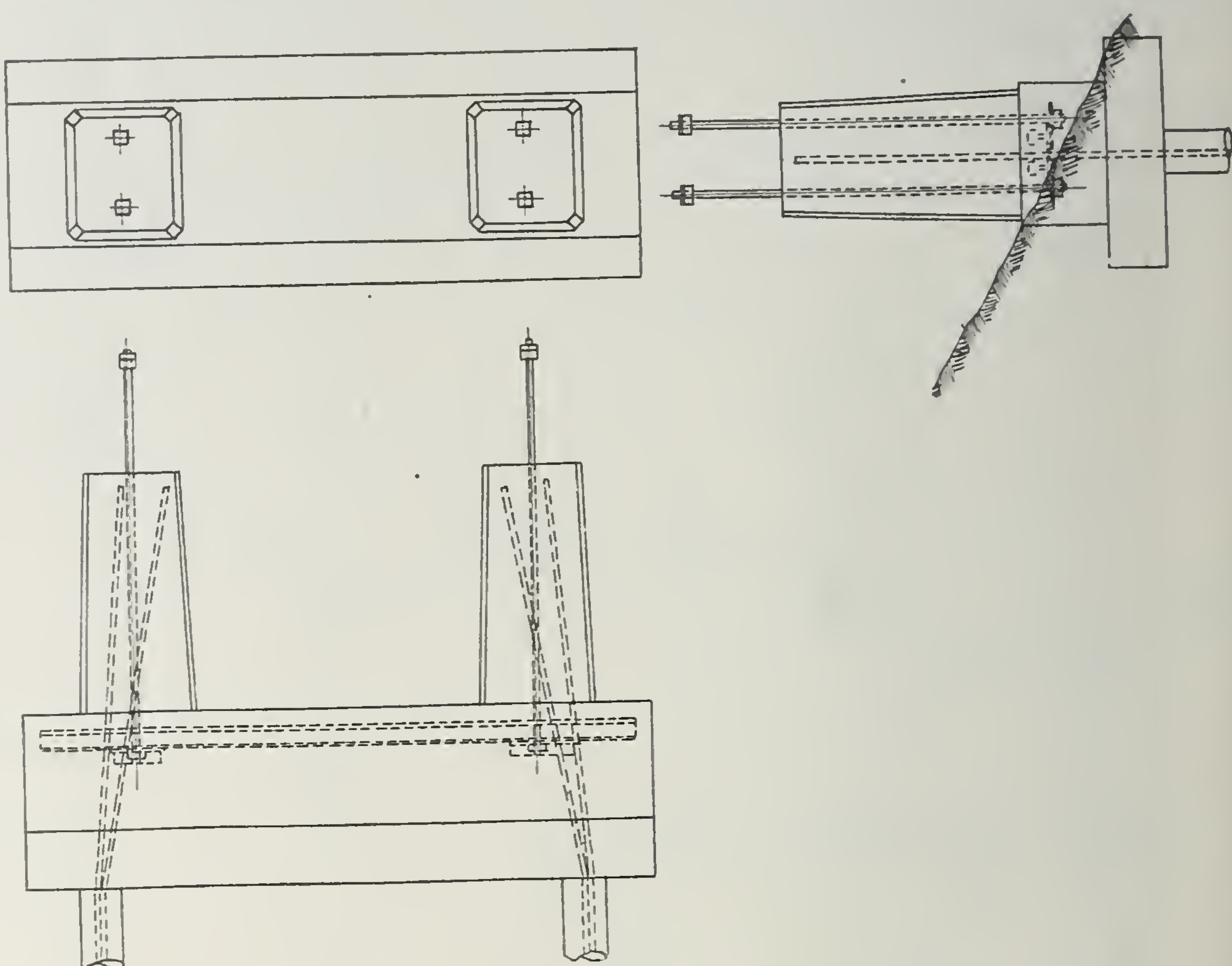

Fig. 3. Foundation on Slope of Fill.

In many cases on steep fills, a firm bearing could not be secured 18 feet from center of track and 4 ft. 5 in. below top of rail. In such cases the form shown in Fig. 3 was used, excavation being carried down as far as was necessary to bring the outer edge of the sub-base in good material, and the height between sub-base and pedestals filled by a base 30 inches wide, which is sufficient to carry the pedestals and embed the reinforcing steel and old rails. This type of construction proved to be almost as usual as the standard type, as a large proportion of the Panama Railroad is on embankment due to the fact that it crosses the water courses on the east side of the Chagres and

Rio Grande valleys, for over half its length; the Canal, of course, occupying the valleys on both sides of the Cordilleras.

Another modification of the standard type was made in crossing a tidal swamp between Gatun and Cristobal. In this case the surface soil, a black organic mud, would not carry the weight of the structures, and four piles under each footing were driven to rock by drilling, casing, and filling with concrete. The longest of these piles was 120 feet, and the average for three miles (54 towers) was 50 feet. The original builders of the Panama Railroad laid a pontoon of logs across this swamp, and the present fill has been gradually brought up about four to six feet above sea level. Wash drill borings at the site of each foundation showed black mud with rotted swamp grass and reeds for ten to twenty feet, then the logs of the original pontoon, badly rotted and crumbling in the air, then from ten to thirty feet of coral sand mixed with mud, then a layer of clear beach sand over the sandstone. The penetration of drilled piles was checked against the wash drill borings, and each hole was driven 3 feet into the rock. The holes were made with Star Well Drills, formerly used in Culebra Cut, and 8-inch casing was driven the full depth, using a long cast iron sleeve to keep the joints in line. The term "drilling," in this connection, is a misnomer, as the operation consisted in driving a joint of casing, stirring up the mud and sand with the bit, and mucking out the hole. Each hole was cleaned out with a hand bailer just before concrete was placed, and expanded at the bottom with a half stick (8 oz.) of 45 percent dynamite, which had the effect of bringing up most of the thin mud and water at the bottom of the hole. Concrete for these holes was mixed with 25 percent extra cement as a factor of safety.

The organization employed in constructing these foundations included the field engineering parties, the construction gangs proper, and the clerical force of timekeepers, field cost clerks, and material and property clerks. Construction was started with a small force, which was rapidly increased to a maximum of 500 employees, the increase being, of course, mainly in the construction gangs. For purposes of accounting and record, the mile, as marked by the Panama Railroad mile posts, was used as a unit, each track span bridge being designated by

a serial number beginning at the mile post north of it, as 7 M-1, or 23 M-16.

The first field work was the location of towers along the center line of track. Starting at a point fixed by the Chagres River bridge, towers were spaced uniformly 300 ft. apart on tangents and curves of 2 deg. 1 min. or less, 250 ft. apart on curves and from 2 deg. to 5 deg., inclusive, and 200 ft. apart on curves over 5 deg., of which there are only four on the entire route. The chaining was done on center line of track, and stakes set on center and ten feet each way on the tangent at

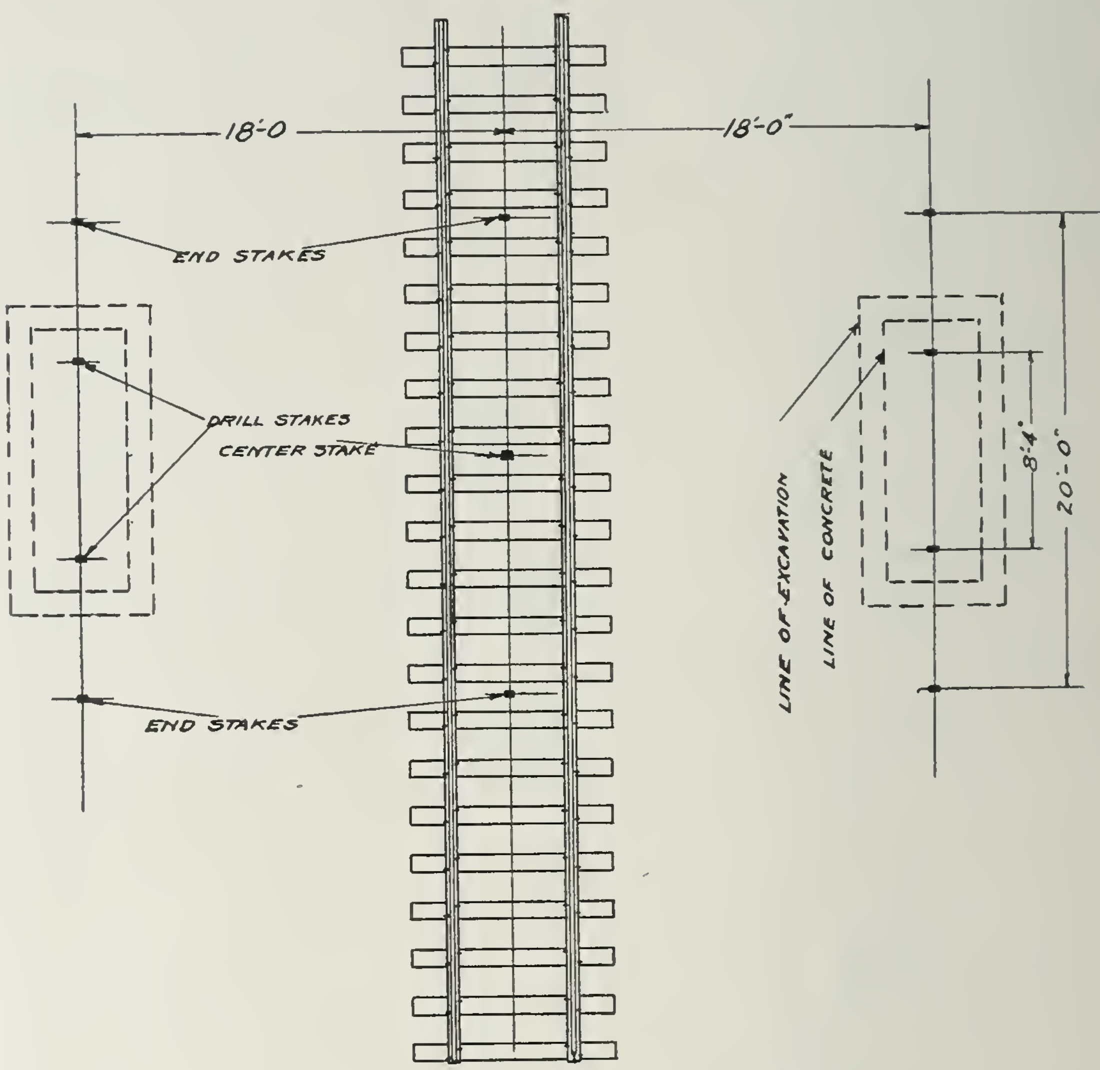

Fig. 4. Layout of Stakes.

this center. From these "end stakes", a rectangle 20 by 36 feet was marked out, the corners on one side of the track giving both alignment and spacing for the anchor bolts and forms. Between the "end stakes", "drill stakes" were set at the point where holes for the anchors were to be drilled, 8 ft. 4 in. apart. It soon developed that the end stakes were liable to be disturbed by men working around the dirlls; hence they were usually placed after drilling was finished, only drill stakes being set on

the first survey. A full set of line stakes appeared as in Fig. 4, and a good instrument man with West Indian negroes as chainmen and stake men can set twelve bridges in an eight-hour day. As the equal spacing of supports is quite essential for satisfactory catenary trolley construction, one or another of the three standard spans was staked according to the rule above given.

To obtain clearance at turnouts, station buildings, culverts, etc., it was occasionally necessary to use a shorter span than 300 feet on tangents and light curves, and in such cases the next shorter standard span was staked, the bridge was moved laterally, or the obstruction removed, the only exception being sub-station dead-ends and one 334 ft. span across the Gatun River. Field book records of chaining and stakes were kept, and the Panama Railroad stationing of each track span bridge recorded.

In general, the foundations were placed 18 ft. each way from center-line on single track, and 13 ft. from center-line of main track on sidings. As sidings are spaced 14 ft. from the main track, the opposite foundation is 9 ft. from center-line of siding, the standard 36 foot wide bridge being used in 791 cases. Twenty bridges of the same type, but 22 feet wide, were employed in the approaches to Gatun and Cristobal sub-stations, in crossing the Chagres River bridge (suspended from the bridge girders) and over the hill pierced by Miraflores tunnel. Five bridges with a span of 39 ft. 6 in., and five bridges 84 feet high, were used in special cases making a total of 821 towers.

The first operation of construction work was to drill the holes for the concrete anchors. Star Well Drills, style No. 15, of the portable type used in Culebra Cut, each having its own boiler, were employed, working in pairs, one drill on each side of the track. The pairs of drills were spaced approximately a mile apart, one white foreman in charge of three pairs. Each pair of drills was in charge of a negro sub-foreman, and twelve laborers, the laborers laying out runways, building cribbing on the steep sides of the fills, carrying water for drill boilers, and moving the outfit ahead. The drills were pulled ahead by their own engines winding up a manila line tied to the track ahead of the next "spot", the runways of 3 ft. by 12 ft. plank being laid out on the ground or on cribbing while the machine was

drilling. This moving was difficult and hazardous at times, on the sloping berm of narrow fills, and comprises from 50 to 80 percent of the cost of drilling. The planking and old ties for cribbing were moved ahead on push cars on the track, at a considerably less cost than they could have been moved by hand.

All drill holes were cased with light 8-inch pipe, except in solid rock, to avoid the possibility of the hole caving in before or during concreting, as every span is required to be an anchor span. To the best of my knowledge and belief, only one hole—the first one—is open to suspicion.

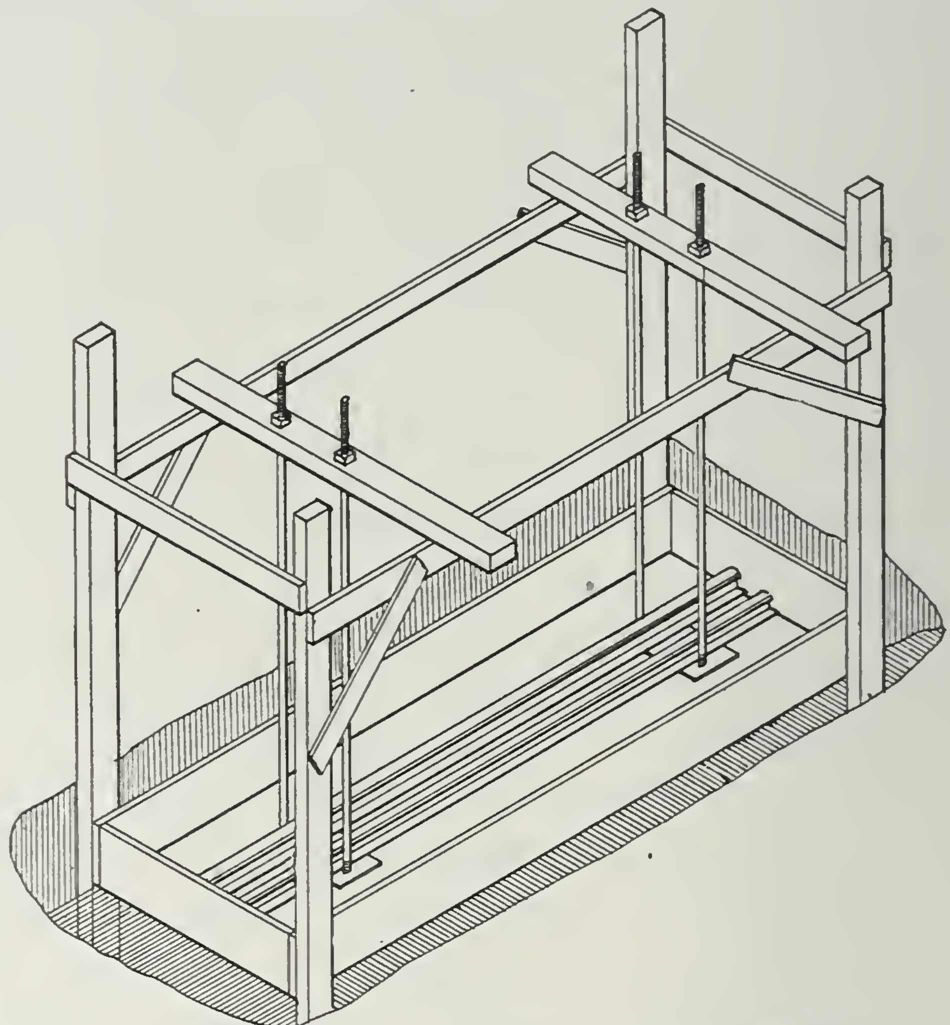

Fig. 5. Isometric View of Form for Foundation.

After the drill moved off the hole, a detachment from the concreting and labor gang excavated a pit 6 by 13 feet to grade, or lower if necessary to secure a firm footing, the drill holes being carefully plugged with a bundle of twigs to avoid dropping loose material into it. The engineer next set a grade stake with its top at the correct elevation for bottom of pedestals, and either checked or set the end stakes, 20 ft. apart on center line of foundation. The iron men then came in, and, after a stick of dynamite had been set off in the hole, measured the

depth and cut reinforcing rods to fit. One stick of 45 percent dynamite or Trojan powder, set off by a hand magneto, sufficed to clear the hole and expand the bottom to an approximate sphere of 2 feet diamater, in fill or clay material. In rock, the "springing" was done twice, to insure a large pocket. The carpenters then erected the form for the sub-base, and a stiff frame for aligning and supporting the anchor bolts, bringing the top of the form level with the grade stake, and the top of the side rail of the frame five feet higher. A light wooden template, twenty feet long, was then laid along the top of the frame, the end rails being placed 6 inches above the side rails to support it, and the center marks on its ends were adjusted over the tracks in the end stakes by means of plumb-bobs, and the templates tacked in place. A 3 in. by 6 in. beam, with holes bored 14½ in. apart to fit the anchor bolts, was next lined up exactly under the holes in the template and spiked to the side rails, the template removed, and the alignment of all bolt holes checked with a steel tape, across the track and longitudinally. A variation of ⅛ in. was allowed, as being the practical limit of accuracy of a tape with a West Indian at one end. The construction of this form is shown in Fig. 5.

The iron men then took charge; having previously exploded a stick of dynamite in the hole and measured the depth, they next lowered the reinforcing rods in the hole, dropped the bolts through the holes in the 3 in by 6 in. beam, put the plates on the bottom, and laid the two old rails in place. The tops of the bolts were brought to grade by running the nut at the top up or down, each bolt tested with a carpenter's level for plumbness, and a split template tacked across the top of the sub-base form to hold the alignment during concreting.

Reinforcing steel was cut and bent and minor repairs to tools and equipment used in concreting were made in portable forges sheltered by a corrugated iron roof, the "shop" being moved about a quarter of a mile at a time by the iron gang on a push car. Saws, shovels, picks, cold chisels, etc., were sharpened in this shop during off times of the day, and the boss warmed his otherwise cold coffee on the forge at noon. If a fortuitous native shack could produce a chicken, the surveyor, the drill foreman and (if he heard of it) the general foreman,

might be seen at the shop during noon hour consuming an impromptu feast instead of the usual cold lunch.

All forms, including the bracing and framework to hold the anchor bolts, were made easily removable, and were used over and over until worn out by nail holes or the rough and tumble handling they received when unloaded to clear a train bearing down on a push car load moving ahead. The placing and removal of forms was done by West Indian negroes under the

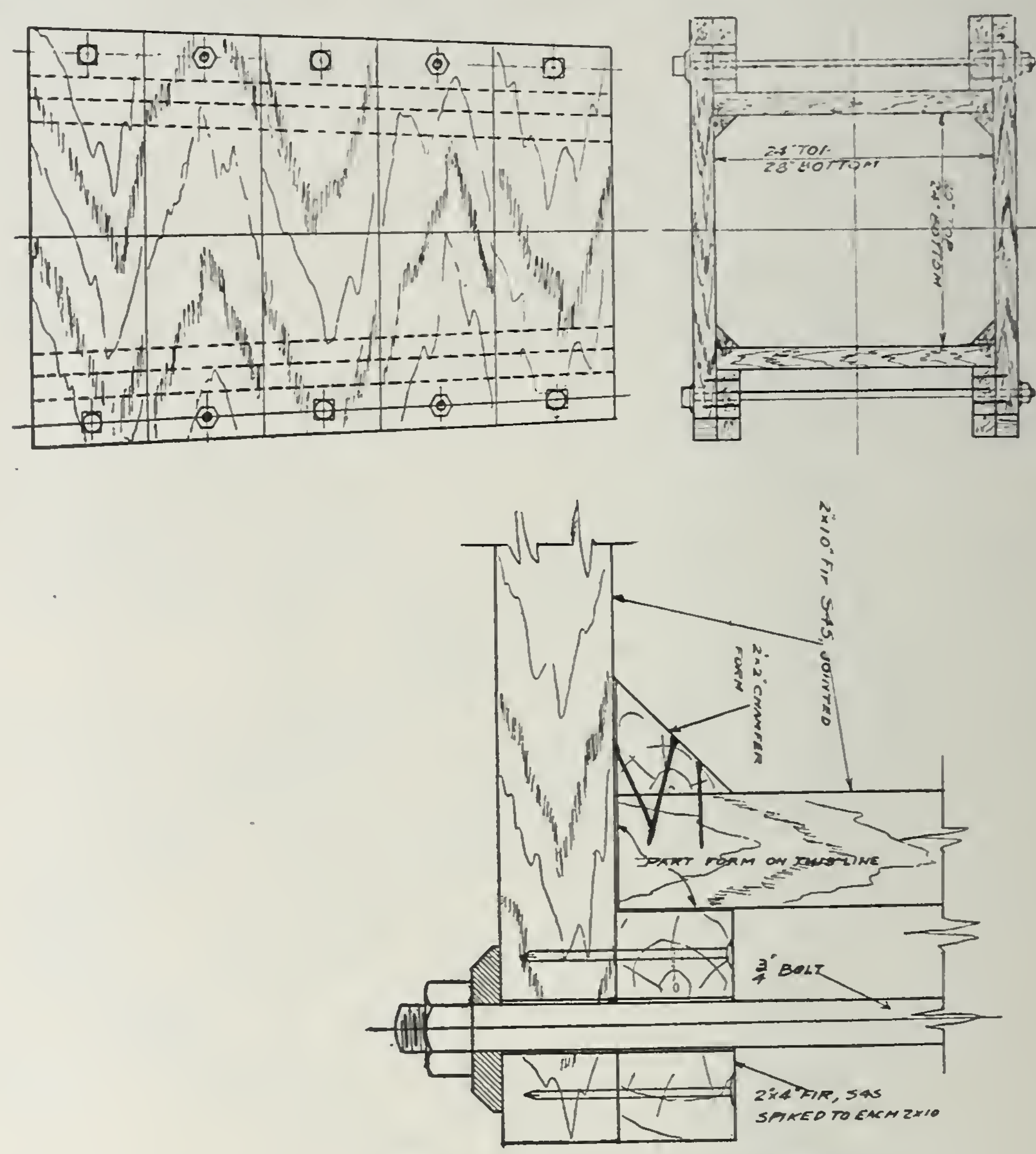

Fig. 6. Portable Form for Pedestals.

direction of a white American carpenter, a gang consisting of ten carpenters, four iron men, two flagmen, and the omnipresent "aguatero," or water-boy. The water-boy deserves special mention, as it is no simple or unimportant matter to find good drinkin water for twenty negroes working under a Panama sun along the track. The boys were under twelve years of age, and I have known them to carry a five gallon "Standard Oil" tin full of water for a mile and a half. The British negro will not

drink anything he thinks will give him "feevah", and he can't work without water. Springs, clear running streams, and the public water supplies were used for drinking, although the long suffering star drill boilers and concrete often had to accept much less carefully selected liquids.

Forms and irons being in place, the next operation was mixing and placing concrete. All concrete was hand mixed, the materials being either (1) Chagres River gravel, not washed or screened, but fairly clean and well graded as it came from the dredges; or (2) crushed trap rock of a size to pass a 2½ in. ring, mixed with one half its volume of clean sand.

No attempt was made to determine percentage of voids in this stone, as tests made previously during construction of the locks showed it to average about 50 percent voids. A 1 to 5½ mix was used with the gravel, and a 1-2½-5 with the sand and stone.

The gravel and stone were dumped one rail length from the location of each foundation, using 12-yard Western or Oliver dump cars. One load of sand was dumped half way between two piles of stone, as only half as much sand was required. The mixing plant consisted of a mixing board 9 feet square, of 2-inch lumber on 3 in by 5 in. stringers, the stringers projecting as handles for moving the board. Runways of 2 in. by 12 in. rough plank were laid from the sand pile and stone pile to the board. A barrel for water was set along side the board, and filled by men with buckets, carrying from streams or ditches, and, for most of the distance from the canal. The operations involved in concreting were as follows: Three men with wheelbarrows load the board with ½ yard of stone and ¼ yard of sand, the stone placed first. Four men with shovels spread the stone and sand evenly over the board, and spread the cement on top. The loaders then proceeded to fill the wheelbarrows and load the board across the track, and the mixers pile the batch up in a steep cone, in the middle of the board. They then "cut" the batch over, dry, into two piles at the side of the board, shovel it back into a ring, and a fifth man pours in the water from the barrel. The mixers then pile the batch into a cone again, wet this time, and "cut" it again, the water man adding water locally as required. When the whole batch has been

finished, and not before, it is shoveled into the form and tamped into the drill holes and around the irons. The mixers then move across the track, and the loaders recharge the first board while the second batch is being mixed.

The sequence and completeness of all the steps of mixing and placing were specified and strictly maintained, as it is not safe to trust to the judgment of the West Indian negro. He learns to do a certain thing in a certain way at a certain signal or cue, and, with supervision, will do just that and do it well.

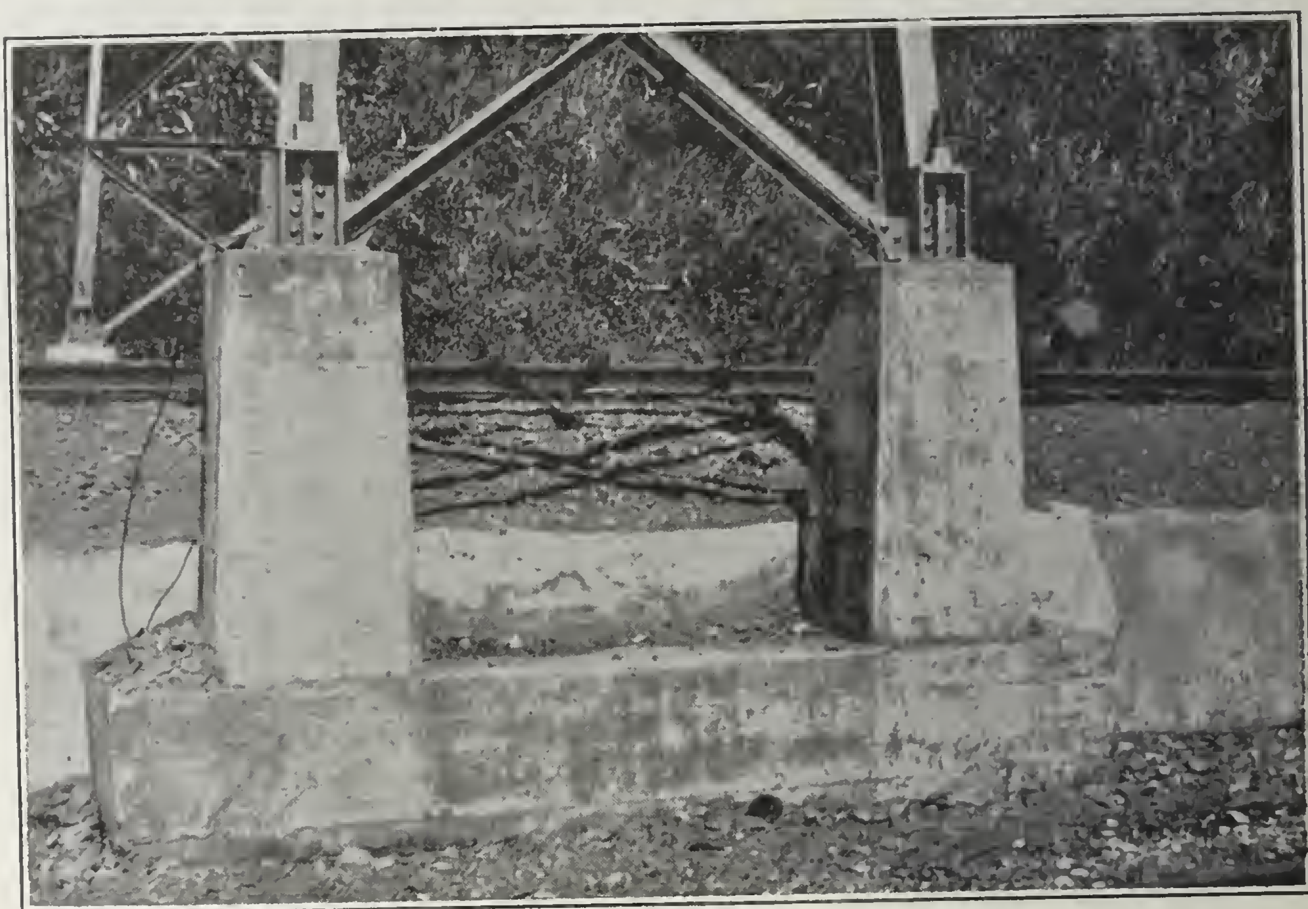

Fig. 7. Foundation with Raised Sub-Base.

The process above described errs, if at all, on the side of over-mixing. A complete cycle takes about 15 minutes, and one gang of four mixers, three loaders, one water man and two water carriers can mix twelve to sixteen yards of concrete, in four different forms, in a day of eight hours.

When the drill holes and sub-base were filled, the concrete gang moves to the next "bridge", while the carpenters set and brace the pedestal forms. These are also removable forms of 2 in. lumber, lined with galvanized iron for smoothness and durability, and fastened with bolts, see Fig. 6.

General views of the foundations and the completed line are shown in Figs. 7, 8, 9 and 10.

Four carpenters, working together, set up, aligned, and braced the four pedestals in about 30 to 40 minutes. The concrete gang, on completing the sub-base ahead, returned and filled the four pedelstals, the carpenters, in turn moving ahead.

Fig. 8. Foundation on Slope of Fill.

Forms filled one day were removed the next, this removal of forms being the first work of the day for the carpenters. As the various pieces were removed, they were piled up beside the track, and moved ahead by push car near to the next open excavation, where they were cleaned with wire brushes, excess nails pulled, and re-erected.

A detachment from the excavating gang finished the foundation by backfilling to the level of the sub-grade, cleaning ditches, disposing of surplus sand, stone, or gravel, and cleaning up the right-of-way. Any surplus iron or lumber were piled up to be removed by the work train.

One of the principal difficulties encountered was the distribution of material in small lots all the way across the Isthmus. Another difficulty was in getting the men from their homes to the widely separated working points. To take care of these two features, a work train, in charge of a qualified crew under the direction of a material foreman, was employed throughout the job. Material was shipped via the Panama Railroad to stations along the route, and handled by the material foreman to the various gangs. As soon as the engineering parties had marked out the location of towers, gravel or stone, and sand, were hauled out and dumped at each bridge. Reinforcing steel, old rails, anchor bolts, and form lumber, were unloaded in piles about four places to a mile. Coal and casing for the drills were unloaded about eight places per mile, sheets of old corrugated iron roofing, some of it left on the Isthmus by the French canal diggers, were laid on the ground to prevent loss of coal.

Cement was unloaded into portable sheds, 8 ft. by 8 ft., with a capacity of about 400 sacks of cement. Two of these were placed in each mile, and refilled as required. The sheds were built of 2 in. by 4 in. and 2 in. by 6 in. lumber, with sides, roof and door of corrugated iron roofing, the floor not attached to the walls. They could be lifted bodily by ten men, and were handled either by the train or on push cars.

Saturday each week was devoted to the distribution of small tools and supplies, and the collection of empty cement sacks. Each foreman was required to hand a list of his needs to the general foreman or material foreman on or before Friday, for the next week. Such material as was not on hand was secured from the Quartermaster's storehouses on Friday, and delivered on Saturday by train.

On completion of a mile, the entire outfit of each gang was loaded on the train, hauled to a new location, and set down ready for work. The drills, of course, completed the mile first,

and were moved first, usually four or six drills at a time, including all those under one drill foreman. The concrete gangs followed two to five days behind the drills. A unit organization included two drills operated by one gang, one carpenter and iron work gang, and one excavation, concrete and backfill gang. An engineering party kept stakes set ahead of two or three unit gangs, and recorded the elevations, spacings, and progress behind them. Five such units were organized and continued until near the completion of the foundations.

Fig. 9. Completed Line along Miraflores Lake.

In addition to the distribution of material and supplies, the work train made a trip morning and evening as labor train, taking men to work and bringing them in at night, over about half the line. Labor trains operated by other departments of the Canal work were utilized elsewhere. For twelve miles near Frijoles, a camp was established, as the nearest town was fourteen miles away—too far for efficient labor train service. The camp at Frijoles was erected by the Quartermaster's Department on the edge of Gatun Lake, and consisted of nine tents, 20 by 40 feet, for "silver" (negro) employes, and five tents, 14 by 14 ft., for "gold" (white American) men.

All tents were floored and screened, and provided with flies for protection against tropical sun and rain. A branch of the Panama Railroad commissary was established where food supplies could be bought, and the silver men did their own cooking. The gold men clubbed together to operate a mess, the cook and waiter being paid by the Commission, and supplies bought at the commissary.

Test loads were applied to four foundations, at points where conditions were least favorable, by piling on pig iron in excess of the load due to the towers. In no case was any settle-

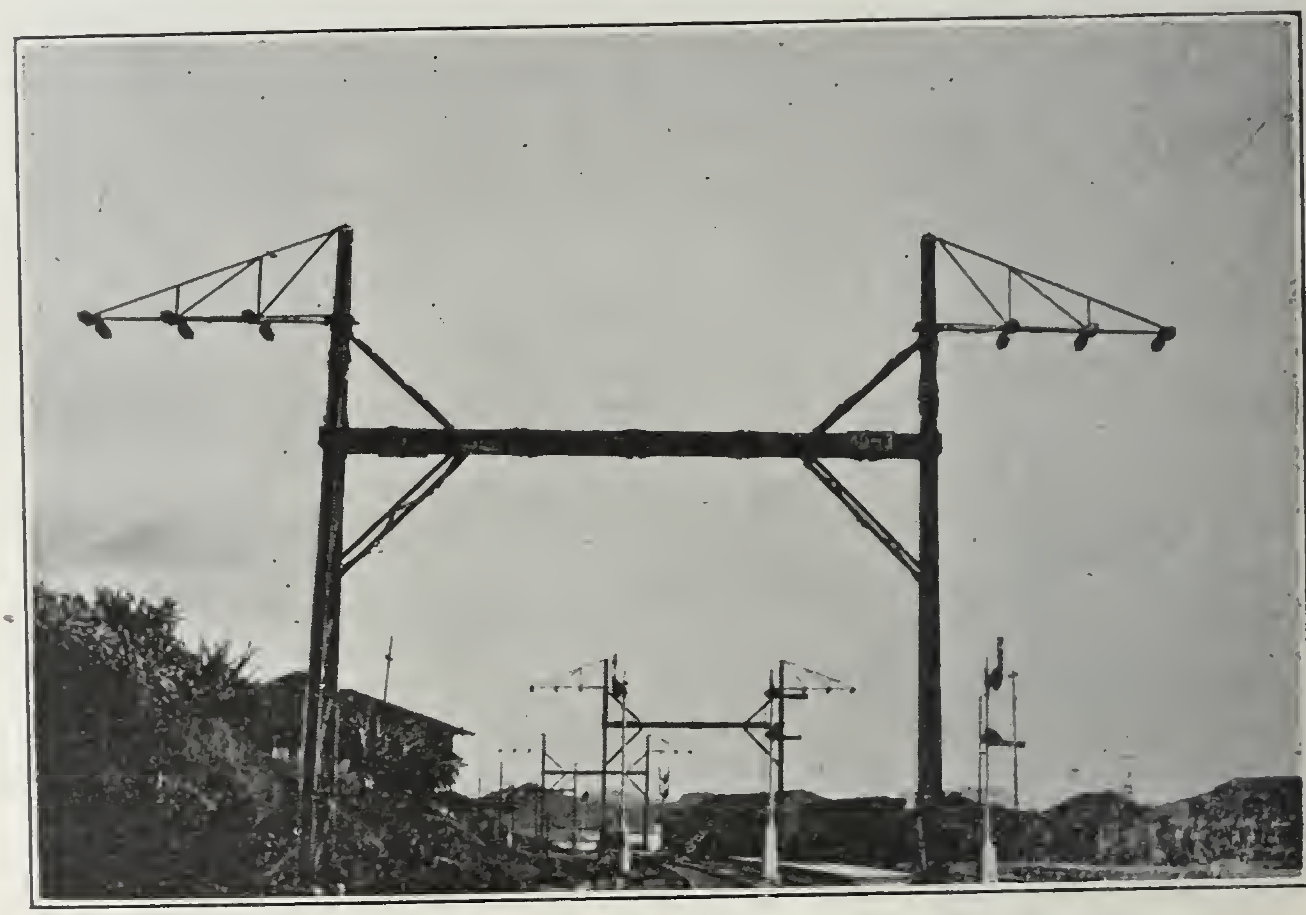

Fig. 10. Curve at Pedro Miguel—Strain Insulators.

ment noted, elevations being taken and measurements checked at frequent intervals. At least two sets of readings were taken with wye level on each anchor bolt, and distances across the track were checked at the same time. In three cases sliding of the fill moved the foundations out of line and grade, and it was necessary to partially wreck and repair them.

The appended diagram of costs, Fig. 11, includes all work on which completed cost data is available at the time this article is written. Miles 4 and 5 are mostly in the tidal swamp between Gatun and Colon. Work was started on Miles 34 and

35, cost figures for which, therefore, involve factors of new organization and inexperienced labor. The other miles shown, however, are fairly representative of average conditions on an average railway, except for the condition of climate.

The principal interest attaching to the type of foundation here described is in the adaptability of this type of foundation to tower structures in general. A usual condition of such structures is that the wind load and other live loads are applied more or less horizontally, producing a force-couple tending to depress one side and lift the other side of the tower. The ex-

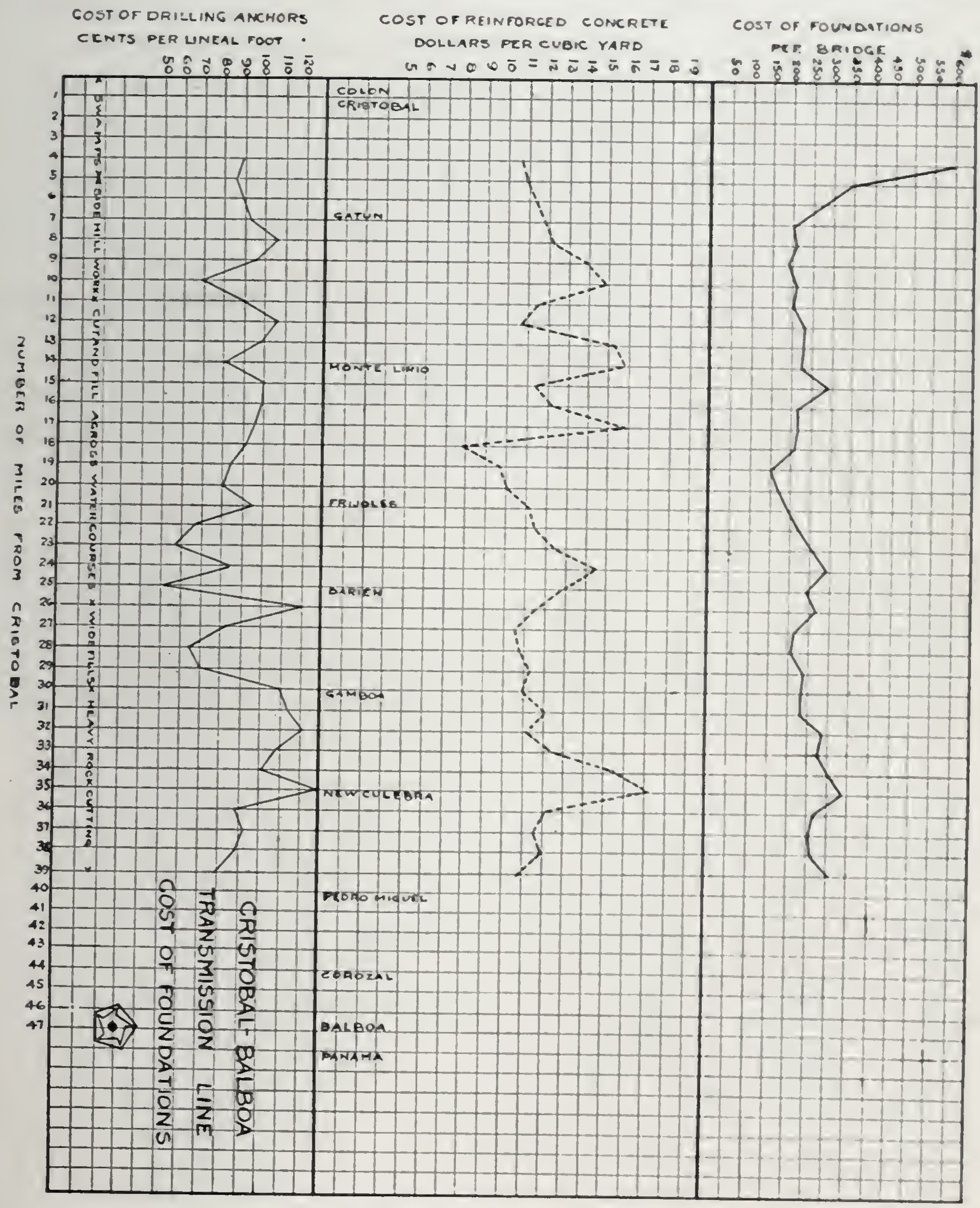

Fig. 11. Cost of Foundations.

panded anchor pile, surmounted by a suitable pedestal, meets this requirement quite exactly.

The piles can be made by boring with a post hole auger, where soil conditions permit. This was done on the Isthmus in places where clay cuts of 1000 feet or more length were found. The auger hole is not so easy to case up, however, and requires firm ground. If ground is loose, it will fall into the hole during concreting, and it is liable to pinch off the pile.

In locations where transportation of materials for concrete is laborious and expensive, as on long cross country transmission lines, for isolated anchor towers on lines using wooden poles, for special installations at sub-stations, for track spanning bridges for electrification of existing steam railroads, and other similar kinds of foundations requiring strength against downward and upward pressures, the expanded pile, surmounted by a pedestal, should be both serviceable and economical.

The foundations herein described were designed in the office of the Electrical and Mechanical Engineer of the Isthmian Canal Commission, and built under his direction. The writer was General Foreman, in charge of the field engineering, construction, and clerical organization in building the foundations.

POSSIBILITIES IN TECHNICAL PHOTOGRAPHY

By Frederick Henius*

Photography has been made popular and its operations simplified by the introduction of the kodak in connection with the well known slogan: "You press the button, we do the rest". Ever since the Eastman Kodak Co. started to manufacture the kodak, which was the name for a small camera, about twenty years ago, we have been able to take pictures by just snapping the shutter; no focusing was necessary, as the lens was of very short focus. One could load the camera with a spool of film and remove this whenever necessary in broad daylight, eliminating the dark room entirely. You could then have your films developed by a professional photographer, at a very small expense, who would also make the prints. Shortly afterwards, the Eastman Kodak Co. started to manufacture Velox paper which could be printed by gas or electric light.

There is now hardly a home in which we cannot find a kodak, and it is considered as a means for pleasure. There is no doubt but that these cameras have hurt the professional photographer, especially the portrait photographer. The technical photographer, however, has not suffered very much, especially the one who knows his business.

Photography is a science and art, although it may not appear as such. It has done more, I believe, for our education than any other science. Just think of the beautiful illustrations which we find in all our magazines and scientific books. Think of what photography has done for astronomy, scientific researches for the medical world, and last, but not least, for the moving picture world. It is now possible to study life and customs in foreign countries with the camera, and these pictures bring before us the scenery and architecture and the way these

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people live; they show us life-like the manufacture of various industries, etc. The well known lecturers appearing in our city with their interesting and highly educating travelogues, which are given before capacity houses, would be entirely lost without photography.

Let us consider what constitutes technical photography and for what purposes are such photographs used.

Technical photographs are taken of machinery, construction work, interiors and exteriors of buildings, manufacturers' products and astronomical subjects, then, we have photo-micrographs, X-ray photographs and other specialties too numerous to mention.

Each of these branches require a special study, and to master them you must experiment until you know; you cannot learn it by reading books. The technical photographer, in order to be successful, should have a mechanical mind, and if possible engineering experience. He must be able to suggest, and if his suggestions are carried out, should shoulder all responsibility. He should use the very best outfit and the best plates, chemicals and paper. He must be positive as to his exposures, so that he will not have to take the pictures over again, as many manufacturers go to a great expense in order to secure photographs of their products and plants and, furthermore, the subject may have been shipped right after it was photographed.

It may be well to learn at this point of what a proper photographic outfit should consist. The camera should be rigid and weight should not be sacrificed for strength. It should have an extreme rising front and swing back and provided with long bellows. The best size to use is 8 by 10 inches, and such a camera should have at least a 36 inch bellows. The tripod should be strong and rigid.

The next most important part is the lens. There are many excellent lenses, mostly of foreign make, but to advise you which make to use would be quite difficult. It depends entirely on what you are going to use the lens for. One lens will not do for every branch of technical photography. However, nothing but an "Anastigmat" lens should be used and an aperature of *F* 6.8 is fast enough.

What is an anastigmat lens? It is a lens in which the

astigmatism, a defect inherent to all the older form of lenses, has been practically eliminated. This has been done by using the well known Jena glass, made in Jena, Germany. Astigmatism means "without a point", and as used with reference to the lens, may be defined as the ability of a lens to bring vertical and horizontal lines (such as a plus sign boldly printed on a white card) to a focus at the same time, although both lines lie in the same plane. It is important that you should understand this defect of the ordinary photographic lens, because it is in its correction or elimination that the superiority of the "Anastigmat" over the older lenses is apparent, and also because its elimination enables us to secure sharper definition over the whole image, a greater angle and consequently a greater intensity, with flatness of field and covering power. Such a lens is pretty near perfection and it is the only lens to use in technical photography.

Before we go any further, let us examine the various properties of lenses. You have heard people speak about focal length, aperature, flatness of field, diaphragm, etc. The focal length, or focus, is the distance from the ground glass to the diaphragm when a subject 100 ft. or more away from the camera appears sharp on the ground glass. The aperature is the diameter of the working part of the lens when fully opened. The depth of focus is the property possessed by a lens of giving an equally sharp image of objects situated at various distances from the camera. Correctly speaking, however, depth of focus is not a property peculiar to any particular form of lens, but to a combination of lenses. A lens working at full aperature without being stopped down will hardly produce sharp objects when the objects are at a distance from the camera. By stopping down, however, considerably more depth is secured, but the illumination is sacrificed and consequently the rapidity.

Of two lenses of the same intensity (rapidity), but differing in focal length, the lens of shorter focus will give the greater depth of definition. Of two lenses of identical focal length, but one having greater intensity than the other, the more rapid lens will apparently have less depth of focus, but when this lens is stopped down by the use of a diaphragm to the same rapidity as the slower lens, the two lenses will have the same depth of

focus. In other words, depth of focus with any given stop is an invariable quality in different lenses of the same focal length, regardless of their construction.

The diaphragm, or stop, plays quite an important part in the use of lenses. It consists of a piece of blackened metal, with a circular aperature at the center, which is placed before the lens if it is a single lens, and between the two elements if it is a doublet. An iris diaphragm consists of several segments of a circle of metal or vulcanite, working on pivots attached to a ring in the lens mount. By rotating the ring, the circular aperture formed by the segments may be made smaller or larger at will. The diaphragm evens the illumination of the plate and increases the defining power of the lens over a large area and gives greater depth. The volume of light that passes through the diaphragm is proportionate to the square of the diameters.

The first maxim may be simply illustrated. If the area of the largest stop of a lens be two square inches, it will permit the passage of twice the amount of light of a diaphram whose area is only one square inch. Therefore, to get the same result. the exposure with a smaller stop should be double that with the larger one and vice versa. The second maxim may be illustrated thus: Suppose the largest stop of a lens has a diameter of two inches and another stop of the same lens a diameter of one inch. One might assume that the smaller would require double the exposure of the larger stop; but maxim one says the volume of light that passes depends upon the area of the stop and not upon the diameter. So we supply maxim two; that the areas of circles are proportionate to the squares of the diameters; so that the area of the larger circle is four times that of the smaller and, therefore, passes four times more light.

We have various makes of diaphragms which have been adopted by the various makers, but the most popular ones are the *F*-stops and the *U. S.* stops. For technical work a lens working at an aperature of *F* 6.8 is fast enough, and enables one to take instantaneous pictures as fast as a hundredth part of a second. The *F*- stops on the lens working at *F* 6.8 full aperature, which means full opening, are graduated as follows: *F* 6.8, 8, 11.3, 16, 22.6, 32, 45, and 64. Using an *F* 16 diaphragm means that the opening in the lens is $\frac{1}{16}$ of its focal

length. It is hard to determine which is the proper focal length of a lens to use for certain subjects. It is governed entirely by the distance from the subject to the lens, and this distance only determines the perspective. Let me at this point impress you with the fact that perspective does not depend upon the lens used, but is governed entirely by the distance from the subject to the lens and nothing else. If you have your camera placed, say, 20 ft. from the subject, by using a 16-inch focus lens you secure an 8-inch image on your ground glass. You will get a 4-inch image of the same subject by using a lens of half the focus, which is 8 inches, but the perspective is exactly the same as the camera has not been moved from its original location. If we now move the camera back so as to obtain 40 ft. distance from the subject instead of 20 ft., but still using the same lens, we will get a 4-inch image, or half of what we had before, but the perspective is different.

You have heard people speaking of wide angle lenses. Any lens, that is to say, an Anastigmat, may be used as a wide angle lens; it depends entirely upon its focal length in relation to the plate for which it is used. An 8-inch focus lens, which is generally furnished with a 5 by 7 camera, will give approximately 50 degrees. If used on an 8 by 10 plate it will give about 70 degrees, and in this latter case the lens would be called wide angle. For photographing tall buildings an extreme wide angle lens is generally used and these lenses are especially made for that purpose and work at a very small aperture. The Goerz people have a lens working at *F*-22. A 2⅜ inch focus lens of this series will cover an 8 by 10 plate, giving an angle of 135 degrees.

There are several different brands of plates and the proper plate should, of course, be selected for its proper purpose. For photographing machinery, manufacturers' products and buildings, a double coated plate only should be used, as they prevent halation, which you so often have seen in outdoor views and interiors in which windows are shown. This halation is caused by the light passing through the film and being reflected by the polished surface of the glass. A double coated plate is first coated with a slow emulsion, and after this is dry a fast emulsion is applied on top of it. The light rays, therefore, are

being arrested by the slow emulsion which has about one-fourth the speed of the fast one, and gives the plate considerably more latitude in exposure. Another great point in favor of the double coated plate is its richness in silver, which is a very important feature, especially so for a photographer who knows how to get the very best results in developing. For photographing scenery, oil paintings and other subjects where it is necessary to get color value in black and white, orthocromatic plates with the proper filters should be used. Recently, a color sensitive plate has been introduced by an English firm, and it is without doubt the most wonderful plate in the market for rendering direct color values. I shall later show lantern slides which will illustrate their wonderful properties.

For X-ray photography, a special plate is manufactured; for copying work a slow plate should be used; for instantaneous photography the high speed plate is the only thing to use. One of the most important factors in successful technical photography is the developing. You will be surprised to learn that many photographers cannot develop their plates and a great number of exposures are completely ruined by incorrect developing. A good reason for this is the fact that the average photographer hurries to get his plate developed and you cannot hurry developing; it must be done gradually, watched very carefully; in fact, the plate must be built up in developing it. The majority of plates are developed with too much contrast and the high lights and the details are completely clogged, so that it is impossible to secure a good print. Furthermore, the average technical photographer does not use double coated plates because they are more expensive, more difficult to devolop, and the time consumed in developing, fixing, washing, etc., is twice as much as single coated plates. After the plate is developed, it should be fixed sufficiently and washed in running water for at least one-half hour; after that it should be set up to dry.

The next step is the printing. There are various brands of paper made by several manufacturers, each paper being made in several grades so as to suit the quality of the negative. Most all of the papers used for technical work are gas light papers, and they can be had with different surfaces, from a high gloss to a dead finish.

To tell you how to take technical photographs would be out of the question, as each subject must be treated differently, and it would not be possible for me to explain to you in a few minutes what it has taken me fourteen years to learn. It may, however, interest you to know how to take photographs of machinery, and I shall explain it to you. Suppose we have to photograph a machine in a manufacturers' plant and it is possible to move it. The first thing we do is to secure the correct illumination; the vital part of the machine should, of course, be in the strongest light. In this case we will assume it is the front part. The view to be taken is to be a ¾, which means that we are to see about ¾ of the front and ¼ of the side. The side, or it may be the end of the machine, will, of course, be in the shade. In other words, less illuminated. Still, all the details should be absolutely distinct in the picture. This can be done by using white muslin as a reflector, but care should be taken so as to illuminate this part of the machine properly. A large screen should be put up in back of the machine so that all details are clear and defined, and none of the shop's surroundings show in the picture. It is, in many cases, important that the bottom of the machine stands out distinctly from the shop floor, in which case it is necessary to lay white paper around the bottom. The machine should be painted a deep gray color, but this applies only to the unfinished part. The polished or finished parts should appear as such and no paint of any kind should be applied to these, because the finished photograph should convey to your mind a picture of this machine as it looks.

The next thing to determine is the distance of the camera from the subject and the elevation of the lens from the floor. This distance is, of course, governed by the size of the building and machinery under construction may interfere with setting the camera. Let us assume that the machine is 10 ft. long. We should then use a 24 inch lens so as to get the proper perspective. In using this lens we need a distance of about 30 ft. and we will secure a picture 9 inches long on an 8 by 10 plate. The elevation of the lens from the floor should be such as to enable you to look down at the machine. How much it is impossible to determine, as it depends entirely upon important

mechanical features which may be located on the top. If the camera has to be placed on a platform in order to look down on the machine it will be necessary to tilt it, but in doing so we cease to have the vertical lines of the machine running parallel to each other. It is, therefore, necessary to use the rising front and swing back and the latter must be absolutely plumb, which can be easily determined by the use of a level. By using this swing back, we will, by looking at the ground glass, learn that a greater part of the picture has ceased to be sharp. It is, therefore, necessary to stop the lens down with the diaphragm until the image reaches such a point that all the details of the machine appear sharp on the ground glass. We then cap the lens, insert the plate and make the exposure. If there is any vibration in the shop which is caused by moving machinery, the machines should be stopped as it is impossible to secure sharp definition if the camera or the subject is vibrating.

Technical photographs are made for three purposes: Records, advertising and selling. It may be well to dwell a few minutes upon the advertising and selling value of technical photographs.

Less than a score of years ago the pictures used for illustrations in books, magazines and trade papers were either wood cuts or zinc etchings in line from pen and ink drawings. Compared with the illustrations of today, these were necessarily crude, heavy and inartistic in effect. The really worthy wood engraving was, of course, too expensive for general use; the zinc line cuts were, in turn, dependent for their attractiveness on the skill of the commercial pen artist employed by the engraver. As a result, it was generally lacking in the finer pictorial qualities of the good pen and ink sketch. The great difference between the old illustrations and those of today is due, first, to the widespread use of photography as a method of illustration and second, to the perfection of the half tone engraving process and the modern printing press. By combining these we are now able to use illustrations possessing all the beauty of the wood engraving plus the life and actuality of the photograph. To such a degree of perfection has this use of photography been pushed that the advertising pages of our magazines fairly rival the reading pages in interest and pic-

torial attractiveness. Still more, the usefulness of photography in the illustration of advertising matter is now so widely appreciated that the photograph enters into every well considered scheme of publicity, either to draw attention to the reading matter or to demonstrate the desirability, advantages or actual use of the article advertised.

It is essential that the photograph shall have that quality which will compel attention and help to create a demand for the goods advertised by showing their advantages, uses or attractiveness. Just as the illustration is used to round out and add interest to the story, so in advertising, the illustration must round out the argument of the advertiser, showing the reader how and why, riveting his attention to the thing advertised and adding to its interest. The closer the connection between the illustration and the article advertised, so much the more helpful is the illustration and the more valuable to the manufacturer concerned. Pictures, not records, are sought by the advertiser, and the more attractive the picture, the greater its value from the advertiser's standpoint.

Advertising is really a department of literature and art, and the same elements that cause a book to be read and talked about will cause an advertisement to be read and talked about. Of all the books that are written in a year and the pictures that are printed in the magazines and trade papers, very few remain with us. It is just so with advertising. How much of the great mass of stuff written and printed is really worthy? And how many of the pictures appeal to us so strongly that we can remember them for any length of time?

The spirit of a company should be represented by its advertisements and advertising literature, for the public is inclined to judge the advertiser from this viewpoint; and yet how much of the advertising sent out is inadequate both in conception and execution; and, to make it still worse, poor illustrations often mar rather than improve the reading matter. This can be seen on every hand in magazines and catalogues. The idea is good and perhaps an illustration or two, but the greater part of the work is bad and deters rather than enhances the sale of the advertised goods.

Recently there has been perfected a machine by the aid of

which it is possible to make photographs in reduced or enlarged scale from blue prints, drawings, maps, book pages, etc., direct on photographic paper without the use of negatives. You will readily see the advantage of using such prints instead of taking a number of large blue prints with you. You can have them reduced to 11 by 14 in. and one hundred of these prints would make a book about one inch thick. It is also possible with this machine to photograph pencil drawings and pencil tracings. Another feature of this machine is the possibility of enlarging maps irrespective of color values. I have made magnifications of typographical maps 1 to 20. This process eliminates the use of the pantograph entirely. The copies are exact and, as in all other work done on this machine, checking is entirely eliminated. The paper used can be folded without breaking, which is not the case with other photographic paper. I shall later show a picture of this machine and illustrate its working operations.

In conclusion, it may interest you to hear a few words in reference to color photography, by which I mean photography in natural colors. The Paget Process, which I am using, may be illustrated as follows: Take a transparent glass plate and rule one of its surfaces into rectangles one-eighth inch square; then with a fine brush and transparent aniline dyes of the three primary colors, fill in the rectangles, coloring them in order, red, green, blue, red, green, blue, etc., until the entire surface is a complete mosaic pattern.

Now take a panchromatic negative plate and assemble the two with the emulsion side of the panchromatic plate in close contact with the colored surface of the mosaic color screen. Place them in a plate holder with the glass side of the mosaic screen facing out so that when the plate holder is in the camera the light traverses the mosaic screen before it reaches the panchromatic emulsion. Put a yellow filter in position before the camera lens and expose.

The exposure will probably be from twenty-five to one hundred times that of the ordinary plate, varying, of course, with the dyes used, the speed of the yellow filter and the speed of the panchromatic emulsion.

Separate the mosaic screen and the panchromatic plate and develop the latter by a yellow green light in a soft working

developer. Fix and wash and when dry, make a positive by contact on a slow working plate. Fix and wash and when dry adjust in contact with the original mosaic screen until the proper coloring of the picture is obtained, when you will have transparency in natural colors.

Let us see what has happened. During exposure the yellow filter operated to cut out the ultra violet rays and to subdue the blue rays in the image. Falling on the mosaic screen, therefore, was a colored image of the object corrected for ultra violet and blue. The mosaic screen being transparent, in turn allowed the light forming the image to proceed through and fall upon the panchromatic emulsion, practically unchanged, except that of its color, so in the red part of the image the emulsion was only reached and acted upon by light passing through the red windows. In the green part of the image the emulsion was only reached and acted upon by light passing through the green windows, and in the blue part of the image the emulsion was only reached and acted upon by light passing through the blue windows.

Wherever the light passed through a window, the silver in the emulsion was altered and in developing became more or less opaque, depending upon the amount of light action. On the other hand, in the red part of the image no light passed through the green and blue windows; in the green none passed through the red and blue; in the blue none passed through the red and green. In developing, therefore, these parts became transparent. A negative was thus obtained made up of black, grey and transparent rectangles so arranged as to form an image of the object.

Upon reversing the negative by making a contact positive, an image of the object was obtained, made up of transparent, grey and black rectangles, respectively. Upon adjusting this positive over the mosaic and looking through the two by transmitted light, we saw the image of the object supplemented in the transparent portions by the color or colors transmitted by the mosaic windows.

By following the above explanation through carefully, it will be noted that the transparent portions come only where light of the color of that part of the object corresponds to the

color of the window of the screen through which it originally passed, thus giving us a representation of the object in its natural color.

Thus far color photography has not been of any commercial value excepting in a few instances. I would like you to see three hand colored bromide enlargements which I brought with me for the purpose of showing you how this process could be commercialized. The artist who colored these pictures used as a guide my original 3¼ by 4¼ panchromatic plates which gave him all the color values.

NECROLOGY

THOMAS HUMRICKHOUSE JOHNSON
RALPH ALBREE
JOHN WESLEY BOILEAU
JOHN T. BROWN
HARVEY B. CHESS, SR.
JOHN P. COLLINS
BARCLAY M. EVERSON
JOSEPH FAWELL
MURRAY FORBES
EMIL GERBER
ROBERT MAXSON GREENE
AXEL H. HELANDER
ROBERT M. HOPKINS
GEORGE L. MILLER
RALPH WINTHROP NEWTON
J. WEIDMAN MURRAY
CHARLES EVERETT PETTEE
JOSEPH L. RISACHER
ALFRED SANG
AUDLEY DONALDSON WHITE

THOMAS HUMRICKHOUSE JOHNSON.

Elected Member January 1888.

Director 1891-1892.

Vice President 1893-1894.

President 1895.

Honorary Member March 1904.

Died April 6, 1914 at Pittsburgh, Pa.

Among the many eminent engineers who have honored the Society with membership and official services, and have taken a large part in the development of the profession in Western Pennsylvania, very few indeed hold as high a place as Thomas H. Johnson.

Born at Coshocton, Ohio, January 12, 1841, of parents whose ancestry indicates those physical, mental and moral qualifications which produce individuals of high character and great capacity for useful work, he was fortunate in obtaining a thorough education before beginning his life work.

His father, William Kerr Johnson, of sturdy, Protestant, Scotch-Irish stock, was a native of Dungannon, County Tyrone, Ireland. Born in 1809 and coming to Coshocton in 1821, he became a prominent business man in that community, occupying among other important positions that of organizing director of the Steubenville & Indiana Railway, later a part of the Pennsylvania Lines West of Pittsburgh.

The mother of Thomas H. Johnson was born Elizabeth Humrickhouse, descendant of a family which emigrated early in the Eighteenth Century from the Duchy of Hesse Darmstadt, Middle Rhine Valley, Prussia, and settled in Eastern Pennsylvania and Maryland. Members of this family served in the Continental Armies, and later in State and National Legislative bodies, and the name stood for high character, intelligence and thrift in the communities in which it was found.

Thomas H. Johnson was prepared for entrance to Jefferson College in 1858 by the Rev. William E. Hunt, pastor of the Presbyterian Church at Coshocton, and graduated as Bachelor of Arts in 1861. The College conferred on him the degree of Master of Arts in 1866, and in 1911 he received the degree of Doctor of Science from Washington and Jefferson University, the successor of Jefferson College.

He began his life work as rodman in the engineering corps of the Pittsburgh and Steubenville Railroad in 1861. Two years later he was assistant engineer on the construction of the Steubenville bridge across the Ohio. From 1867 to 1869 he was engaged as assistant engineer, in general work for the Pittsburgh, Cincinnati & Chicago Railway; from 1869 to 1871 in the construction of the Chartiers Railway, now the Chartiers Branch of the Pennsylvania Lines. In 1871,

after the completion of the Chartiers Railway, he was transferred to Richmond, Indiana, and was there engaged in the erection of the Richmond passenger station until May 31, 1872. From May, 1872, to March 1, 1873, he served the company in the general work along its lines; and on March 1, 1873, began the erection of the station at Columbus, Ohio. Upon the completion of this work in March, 1875, he was again transferred to Indiana and throughout that year was in charge of the construction of the Vincennes Engine House and the Richmond Shops.

In the latter part of 1875 he severed his connection with the railroad and opened an architect's office in Columbus, Ohio, and thereafter until March, 1883, was engaged as chief engineer in the construction of the present State Capitol at Indianapolis, Indiana.

In 1883 he again entered the service of the Pittsburgh, Cincinnati, Chicago & St. Louis Railway as Principal Assistant Engineer, a position which he occupied until 1896, when, upon the death of M. J. Becker, he succeeded to the position of Chief Engineer of the Southwest System. In 1901 he became Consulting Engineer for all the Lines West of Pittsburgh, a position which he held until Jaunary, 1911, when he reached the age of automatic retirement.

At the time of his death he was Chief Engineer of the Pittsburgh Chartiers & Youghiogheny Railroad, Chief Engineer of the Chartiers Southern Railway Company, and Special Consultant for the Pennsylvania Lines.

During a long and active life as a constructing engineer Mr. Johnson gave faithful service to his clients, as clearly appears from the weight of responsibilities increasingly placed upon him. In a larger way than lay within the power of many equally faithful, he was able to use his rare qualities of mind and the results of his thorough scholastic training for the collection of exact information, the analysis of new conditions, and the solution of many problems of great importance in his work.

So great was his natural modesty that he did not appreciate the importance of these contributions to engineering knowledge, and made no effort to display them before his professional brethren. His friends prevailed on him to publicly record his experiments on the *"Strength of Columns"* and on *"Tunnel Ventilation"*, but the greater part of his engineering attainments is to be found only in the records of his daily work and in the structures he built.

Mr. Johnson became a member of the Engineers' Society of Western Pennsylvania in January, 1888, and at once took such active part in its affairs as to become a Director in 1891 and President in 1895. The influence of his thorough work and wise counsel, as a member and officer, worked for great good to the then struggling organization, and had much to do with its great development in recent years. It is impossible to record in this space the many things he did, at just the

right time and in just the right way, to preserve the high ideals, increase the usefulness, and strengthen the influence of the Society.

He attended many scientific bodies as representative of the Society, and therein exhibited those qualities of friendliness, cool-headedness, and wisdom, which distinguished him in all his many activities. As the Society grew in strength and multiplied its activities and relationships, Thomas H. Johnson became one of the few toward whom everyone looked in time of stress and uncertainty, or when something unusual had to be considered, or a new path blazed out. The officers who carried the responsibility of Society management durng the past twenty years all feel grateful indeed to him for his aid and comfort, loyal support and gentle admonition, whenever needed.

In March, 1904, Thomas H. Johnson was unanimously elected an Honorary Member of the Engineers' Society of Western Pennsylvania in recognition of the esteem of the members for his achievements as an engineer, and his long and useful service to the Society. Until within a few days of his death he continued an active member of the Society, and his kindly presence was familiar to all who attended the various meetings.

Mr. Johnson was a member of many other organizations, some of which are as follows: American Society of Civil Engineers, The American Institute of Consulting Engineers, the American Railway Engineering Association, American Association for the Advancement of Science, American Society for Testing Materials, The American Geographical Society of New York, American Forestry Association, American Association for International Conciliation, The Pennsylvania Forestry Association (being a member of its Council for some years), Pittsburgh Testing Laboratory, Pittsburgh Alumni Association of Phi Kappa Psi Fraternity, Technischer Verein of Pittsburgh, The Veteran Employees Association, Washington & Jefferson Alumni Association of Western Pennsylvania, Royal Societies Club, of London, Royal Society of Arts, of London, Royal Metrological Society, of London.

The death of Mr. Johnson brought a great loss to the engineering profession, and particularly to the Engineers' Society. Many tributes were made by members and life long friends, among them the following:

"His mind was such a store of knowledge, both scientific and practical, his character so high, and his manner so simple and sincere, that his professional brethren and subordinates, and all with whom he came in contact, were alike amazed at his wisdom and uplifted by his personality, and cheered by his kindliness."

"His chief characteristics were, I think, simplicity, single-mindedness, sincerity, consideration, kindliness and charity, coupled with a singularly sweet disposition, making him, indeed, a lovable companion. His vast fund of well-ordered knowledge was always at anyone's command, and the younger man went to him for advice, counsel, and help

as freely as a child to its father. In contact with his associates, in private discussion, or in committee work, Mr. Johnson's gracious personality was always in evidence, and even when he opposed you, he did so in a courteous and kindly way, and entirely free from offensive personalities.

"John Henry Newman in his essay on 'The Idea of a University' gave a definition of a gentleman which so aptly applies to Mr. Johnson that I quote it:

"'Hence it is that it is almost the definition of a gentleman to say that he is one who never inflicts pain. He is mainly occupied in merely removing the obstacles which hinder the free and unembarrassed action of those about him, and he concurs with their movements, rather than take the initiative himself. * * * * *

"'The true gentleman, in like manner, carefully avoids whatever may cause a jar or a jolt in the minds of those with whom he is cast—all clashing of opinion, or collision of feeling, all restraint or suspicion, or gloom, or resentment, his great concern being to make everyone at their ease and at home. He has eyes on all his company; he is tender toward the bashful, gentle toward the distant, and merciful toward the absurd; he guards against unseasonable allusions, or topics which may irritate; he is seldom prominent in conversation and never wearisome. He makes light of favors while he does them, and seems to be receiving when he is conferring. He never speaks of himself except when compelled; never defends himself by a mere retort; he has no care for slander or gossip; is scrupulous in imputing motives to those who interfere with him, and interprets everything for the best. He is never mean or little in his disputes, never takes unfair advantage, never mistakes personalities or sharp sayings for arguments, or insinuates evil which he does not say out. * * * * *

"'He is patient, forbearing and resigned, on philosophical principles; he submits to pain, because it is inevitable; to bereavement, because it is irreparable; and to death, because it is his destiny.'

"Such a man was Thomas H. Johnson."

Committee { Thomas Rodd,
Samuel E. Duff.

RALPH ALBREE

Allegheny, Pa., Oct. 17, 1872.

Pittsburgh, Pa., Feb. 16, 1914.

Mr. Albree spent his early life in Allegheny and later graduated from Yale University in 1894. After graduation he became a partner in the ornamental iron business started by his brother, Chester B. Albree, and later, when the business was incorporated, he was made

Secretary and Treasurer, which position he held until the time of his death.

He was an enthusiastic naturalist, spending much of his time in his garden, in Western Avenue where he lived, and often surprised his many friends by his intimate knowledge of plant and bird life.

He took a great interest in charities and devoted much time and energy to the North Presbyterian Church, of which he was a trustee.

He was married to Anna Theodora Wood, who with four sons and three daughters, survives him, also two brothers, Chester B. Albree of Pittsburgh and Fred Albree of Boston.

He was an active member of the Engineers' Society of Western Pennsylvania, in which he took great pride and interest and also a member of the University Club, and his death is a distinct loss to the community.

JOHN WESLEY BOILEAU.

Athens County, Ohio, October 27, 1873.

Pittsburgh, Pa., October 7, 1914.

His father was George H. Boileau and his mother Hannah Gibbons. His educational foundation was secured in the public schools of Morgan County, Ohio, but for the most part Mr. Boileau's education was obtained by self study; being a keen observer he soon attained a good working knowledge of economic geology and mining engineering. Mr. Boileau made a special study of the coal measures of the Appalachian Field and in this line a large part of his success was achieved. His maps and data on the coals of this section have been given high consideration for some years past.

Mr. Boileau some time ago became associated with Mr. J. V. Thompson of Uniontown, Pa., one of the largest dealers in coal lands in the United States, and as his representative prepared many reports on the coal in Greene County, Pa., and parts of West Virginia. It was during these studies of Greene County conditions that Mr. Boileau's attention was directed to the matter of freight rates in the Pittsburgh District as applied specifically to coal and coke shipped away from said district, and he became the leader in the action brought by the coal operators before the Interstate Commerce Commission, which resulted in a 10c reduction in freight rates.

Mr. Boileau, by his friendly and genial disposition, had secured for himself a warm place in the esteem of his associates and his untimely death at the age of only 41 is greatly deplored by his friends and co-workers.

He has been a member of this Society since July, 1907, and has taken a deep interest in its welfare. Consequently the Society feels

keenly its loss and wishes to register its sorrow at the death of Mr. Boileau and at the same time to extend sympathy to the bereaved family and friends.

JOHN T. BROWN.

Philadelphia, Pa., April 17, 1845.

Pittsburgh, Pa., May 22, 1913.

He was born in Philadelphia of an old Colonial family. On his mother's side, Mary Randolph, he was a lineal descendant of the Randolphs of Virginia, and through his father he was connected with the Vandergrifts of Oyster Bay.

He was Vice President and General Manager of the Damascus Bronze Co. of the Northside and a veteran of the Civil War.

Mr. Brown was a well-known metallurgist and the inventor of a number of alloys. He was one of the first men to manufacture phosphor bronze in this country.

He had been a resident of Pittsburgh for 18 years and was a member of the Episcopal Church, the Engineers' Society of Western Pennsylvania, the Pittsburgh Railways Club and Elks and was a life member of the Western Exposition Society of Western Pennsylvania.

His widow, Mrs. Elmira Brown; three daughters, Mrs. John M. Snyder, of Hollidaysburg, Pa. and the Misses Linda and Deborah Brown, and one son, John T. Brown, all of Pittsburgh, survive.

HARVEY B. CHESS, SR.

Pittsburgh, 1845.

Pittsburgh, 1913.

He was born on the South Side, Pittsburgh. He was a student of the Western University of Pennsylvania (now University of Pittsburgh), and at the outbreak of the Civil War enlisted in Young's Battery in which he served throughout the war. He then became identified with the business of his father, at whose death, in 1877, he became a partner in nail and tack manufacturing business with his brothers, Walter and Henry Chess. This came to be known as the Consolidated Expanded Metal Co. in Braddock, of which Mr. Chess was Vice President until his retirement in 1907.

Mr. Chess was a machine designer and engineer of experience, having spent more than 40 years in the study and designing of special machinery for his own lines of manufacture.

Mr. Chess was a member of the Third Presbyterian Church and of the Engineers' Society of Western Pennsylvania.

He left a widow, Mrs Annie Boles Chess and two sons, Harvey B. Jr. and Phillip Sheridan Chess.

JOHN P. COLLINS.

Pittsburgh, May 14, 1870.

Pittsburgh, January 21, 1914.

He was educated in the Pittsburgh Public Schools and graduated from the Pittsburgh High School. He was employed in the Pittsburgh Post Office from 1887 to 1891, after which he accepted a position with the Carnegie Steel Co. at the Lucy Furnaces. He was Assistant Superintendent of the Lucy Furnaces in 1900 and later became Assistant General Superintendent of the City Furnaces, which position he held until about a year ago when, upon the retirement of James Scott, he was promoted to the position of General Superintendent of the Sharpsburg Furnaces.

As a blast furnace operator, Mr. Collins made an enviable record, being one of the most successful men in his line in the country. He was a member of the American Institute of Mining Engineers, Iron & Steel Institute, the Engineers' Society of Western Pennsylvania, the Oakmont Country Club, the Stanton Heights Golf Club, Pittsburgh Athletic Association and the Elks. He leaves his widow, Mrs. Kathryn Kleppner Collins and three sisters, Mrs Ella Munns, Mrs. Alice Bradley and Mrs. Bertha Bradley, and three brothers, William, Henry J. and David A. Collins.

BARCLAY M. EVERSON.

Pittsburgh, April 13, 1850.

Pittsburgh, March 4, 1914.

He was a son of the late Wm. H. and Mary Harker Everson, and had been connected with the iron and steel business, his father having been one of the pioneer manufacturers of this section. For several years past Mr. Everson has been engaged in the machinery business, having offices in the German National Bank Bldg. In past years he had been leader of a number of different church choirs, among them the Point Breeze Presbyterian Church and the Second Presbyterian Church choirs. Mr. Everson had also sung in the St. Andrew's Episcopal Church. He was one of the charter members of the Art Society and was a member of the Shady Side Presbyterian Church.

His widow, Mrs. Sarah Marchand Everson; two children, Adelaide and Malcolm W. Everson, and one sister, Mrs John C. Thompson, the latter of East Liverpool, Ohio, survive.

JOSEPH FAWELL.

Sadberge, England, May 3, 1855.

Pittsburgh, Pa., October 2, 1914.

He received his early education and training as a mechanical engineer in England. In 1878 he came to this country and a year later associated himself with Mackintosh, Hemphill & Co. (Fort Pitt Foundry) as chief draftsman. A short time after he was appointed chief engineer. He remined in that capacity until 1902, when he was elected president of the company, succeeding N. A. Hemphill, retired, which position he filled until the time of his death.

Mr. Fawell was regarded as one of the foremost authorities on rolling mill practice and probably was more closely identified with the progress of that industry than any other individual in this country. There are few rolling mills of prominence in this country today that have not some machinery which has been designed under his supervision.

Mr. Fawell was a member of Calvary Protestant Episcopal Church. He was interested in numerous private philanthropies and was a member of several organizations, including the Duquesne Club, Pittsburgh Athletic Association, Pittsburgh Country Club and Crescent Lodge No. 576, F. & A. M.

His widow, Mrs. Elizabeth Fawell; two daughters, Evelyn, wife of Howard S. Evans of the Macbeth-Evans Glass Co. and Laura, wife of Bernard W. Lewis of Moore, Leonard & Lewis; and one son, Joseph E. Fawell of Mackintosh Hemphill & Co., together with one brother and two sisters in England, survive.

MURRAY FORBES.

Philadelphia, Pa., June 23, 1863.

Greensburg, Pa., December 28, 1913.

His father, Dr. William S. Forbes, was Professor of Surgery at Jefferson Medical College. His mother, Celinere (Sims) Forbes, was a sister of J. C. Sims, Secretary of the Pennsylvania R. R. Co. and Judge Clifford Sims of the Superior Court of New Jersey.

Mr. Forbes received his early education at Rugby Academy and at Dr. Farries' School in Philadelphia and entered the Art School of the University of Pennsylvania at the age of fourteen. When he was seventeen he entered the Pennsylvania R. R. shops at Altoona, Pa., where he took the regular four years' apprenticeship course. He was then employed in the shops for some months, being afterwards transferred to Derry, Pa., where for four years he was Assistant Road

Foreman of Engines on the Pittsburgh Division of the Pennsylvania R. R.

He resigned this position in 1888 and went to Greensburg, Pa., where he took charge of the construction of the plant of the Westmoreland Water Co. and continued as executive head of this corporation until his death. Under his direction the plant was extended and, with allied corporations, served the communities along the Main Line of the Pennsylvania R. R. west from Greensburg to Irwin, and south along the Southwest Branch as far as Youngwood. A total of 50 000 people were supplied, in addition to large industrial and mining plants, by the companies in which he was guiding spirit, and this, too, in a section where, because of the broken topography and the dumping of mine drainage into the streams, the operating conditions are exceedingly difficult and expensive.

Mr. Forbes was a recognized authority in matters pertaining to water-works construction, operation and valuation. He was employed in a number of water-works cases, either as an expert witness or as a member of boards of arbitration. He assisted in organizing the Pennsylvania Water Works Association and served for three years as its president. He was also a member of the American Water Works Association, the New England Water Works Association, the Engineers' Society of Western Pennsylvania, the American Society of Mechanical Engineers, and the Union League Club of Philadelphia. He was a Mason and a member of the Protestant Episcopal Church.

In 1893 Mr. Forbes was married to Miss Ethel Parvin, of Philadelphia, who with five children, survives him.

EMIL GERBER.

Reishenbach, Saxony, January 31, 1858.

Pittsburgh, Pa., April 1, 1914.

His father, C. F. Gerber, was born in 1819 and died in 1899. He was a designer and manufacturer of textile fabrics and introduced the use of power looms in his native town. His mother's maiden name was Christliebe Klotz, daughter of Carl Klotz. His ancestors for several hundred years were residents and prominent citizens of Reichenbach, Saxony. His father came to the United States in 1862 and settled in Webster, Mass., and in 1867 his mother came to Webster, bringing Emil and his two brothers, Herman and Carl.

He was educated in the common schools of Webster, Mass., and the Stevens High School, at Claremont, N. H. In the fall of 1873 he entered the Worcester Polytechnic Institute at Worcester, Mass., and was graduated as a civil engineer in the spring of 1876, being at that time only a little more than eighteen years of age.

Mr. Gerber taught school for one year at Southbridge, Mass., and

was employed as a bookkeeper in a corporation store connected with the woolen mills in Webster, Mass., until May 1, 1879, when he was engaged as transitman on the Fremont, Elkhorn and Missouri Valley R. R. In May, 1880, he became Locating Engineer with the same railroad, and in 1881 was promoted to the position of Assistant to the Chief Engineer, Captain James Edward Ainsworth. On August 1, 1881, he was appointed Assistant Engineer on the Blair Bridge over the Missouri River, near Blair, Neb., built by the Sioux City & Pacific R. R., which later became a part of the Chicago Northwestern Rwy. Toward the completion of this work on Nov. 1, 1883, Mr. Gerber was made resident engineer. From 1885 to 1887 he was connected with Mr. Morrison who put him in charge of his Chicago office. During this period he was connected with all Mr. Morrison's important works, among which may be mentioned the Cairo, Memphis, Burlington, Winona, Bellefontaine, Alton and Leavenworth bridges; the Chicago, Burlington and Quincy entrance into St. Louis, and many less important works.

In the spring of 1900 he was made Manager of the Lassig Works of the American Bridge Co. In 1901 he was made Assistant to the President, holding various positions until 1911, when he was made General Manager of Erection, which position, together with that of Assistant to President, he held during the remainder of his life.

He was married on Jan. 3, 1882, at West Roxbury, Mass., to Caroline Herthel, daughter of F. J. Herthel, Sr., and is survived by his widow, a daughter, Mrs. Laura E. Olson of Chicago, and a son, Emil Gerber, Jr., of Pittsburgh, Pa.

He wrote various papers which he presented before different societies.

Mr. Gerber was a member of the American Society of Civil Engineers, American Railway Engineering Association, the Western Society of Engineers, The Engineer' Society of Western Pennsylvania, the Chicago Engineers' Club and the Duquesne Club and Junta Club of Pittsburgh.

ROBERT MAXSON GREENE.

Hillsdale, N. Y., March 30, 1870.

Chicago, Ill., December 5, 1914.

Prior to his entering Rensselear Polytechnic Institute, where he studied engineering for three years, until June, 1892, he had been employed from July, 1887, to Jan., 1889, as Roadmaster's Assistant in the Engineering Department of the Missouri Pacific Railway at Pueblo, Col., and Scott City, Kansas.

From 1903 to 1906 he was designer and estimator for the Cambria Steel Co. of Johnstown, and from 1906 to 1912 as Assistant Engineer

of American Bridge Co., in charge of detail construction of steel and iron work for office and mill buildings, etc., etc. From 1912 until his death he was engaged in private practice as a structural engineer, first in Detroit and later in Winnipeg, Canada. He had been in ill health for the last few years of his life and died suddenly while in Chicago from hemorrhage and heart failure. He was married on Nov. 18, 1896 at Manhasset, Long Island, to Miss Harriette Simpson Horsfield, who survives him.

AXEL H. HELANDER

Vingaken, Sweden, April 8, 1864.

Youngstown, Ohio, October 17, 1914.

Mr. Helander was born in Sweden in the year 1864, and came to the United States quite early. His real start began during his connection with the Southwark Foundry & Machine Company, Philadelphia, where he entered as a draftsman in 1892. Shortly after that time this company purchased the rights to build Weiss condensers in the United States, and Mr. Helander gradually took hold of all the condenser work.

After about four years at Southwark, he went with Frank Roberts & Company, in Philadelphia, where he worked on layouts of rolling mills and power plants. Through this position he became acquainted with the officials of the Colorado Fuel & Iron Company.

In 1899 he was appointed chief draftsman of that company, and went to Pueblo, Col. After a few years he was promoted to the position of chief engineer, which he held until the year 1906.

Mr. Helander had never given up his condenser work and had designed and tested out improvements right along. As a result, he was well equipped to introduce barometric condensers at the Mesta Machine Company, of Pittsburgh, in 1906. Besides acting as condenser engineer, Mr. Helander acted as contracting engineer, and was so successful in sales engineering that he was made Second Vice President of the Mesta Machine Company.

In 1912 he took a similar position with the William Tod Company, of Youngstown, Ohio., and was Second Vice President and Consulting Engineer of that company.

ROBERT M. HOPKINS.

Toledo, Ohio, December 30, 1878.

Geneseo, N. Y., January 11, 1914.

He was educated at the University of Dakota and the Massachusetts Institute of Technology in Boston. He graduated from the latter

institute with the degree of Electrical Engineer in the Class of 1900. Since that time he has resided in San Francisco, Chicago, New York, and latterly in Pittsburgh, as Sales Manager of the Alberger Pump & Condenser Co. of New York City.

He was a member of various clubs and societies, among others Sons of the American Revolution (Boston Chapter), The Technology Club of New York, Pittsburgh Athletic Association, The Illinois Athletic Club of Chicago, the Engineers' Society of Western Pennsylvania and the American Society of Electrical Engineers.

He had been engaged in several important and interesting works of a scientific nature, among them the longest distance electric power transmission plant in the world, located in California, and the recent installation of the great pumps in the new government dry docks at Honolulu, Puget Sound and the Brooklyn Navy Yord.

Besides his parents, he is survived by his brother Charles of Rochester, his sister, Mrs Helen Anning, of Sharon, Pa., and his sister Mary, of Geneseo.

J. WEIDMAN MURRAY.

Lickdale, Lebanon Co., Pa., October 17, 1853.

Pittsburgh, Pa., July 16, 1914.

He located in Pittsburgh in 1876, forming a connection with the old Keystone Bridge Works. Subsequently he became identified with the Weimer Machine Works, Lebanon, Pa. He later moved to Birmingham, Ala., where he was Mech. Engr. for the Tennesse Coal, Iron & Railroad Co. He returned to Pittsburgh nineteen years ago as manager of the E. P. Allis Co., and when this company was reorganized as the Allis-Chalmers Company he continued as the Pittsburgh representative of the consolidated concern.

Mr. Murray was a member of Tancred Commandery, Knights Templar Pennsylvania Consistory, Scottish Rite, Masons; Syria Temple of the Mystic Shrine; Duquesne Club, Pittsburgh Athletic Association; American Iron & Steel Institute, American Society of Mechanical Engineers, Engineers' Society of Western Pennsylvania and the Steitz Club of Lebanon.

His widow, one son, Leigh C. Murray, of Pittsburgh, one daughter, Mrs Fergus C. O'Connor, of Parkersburg, W. Va., one sister, Mrs. E. P. Ewing, of Chicago, and a brother, L. Weimer Murray, of Lebanon, survive.

CHARLES EVERETT PETTEE.

Ilion, N. Y., December 21, 1848.

Pittsburgh, Pa., May 21, 1914.

When the Civil War broke out, and at the age of 16, he enlisted in the Fourteenth Regiment, New York Heavy Artillery, and served from 1862 to 1865. He mustered out with honor and with a proud record as a soldier.

After his return from the war, he entered the employ of the Remington Arms Co., at Ilion, N. Y., and remained with that company for 25 years. He then became associated with the G. N. Pierce Bicycle Co. of Buffalo, N. Y., and subsequently with the Westinghouse Machine Co. at East Pittsburgh. From 1908 to 1911 he was with the G. M. Herman Pneumatic Machine Co. at Zelienople, and at the time of his death was a manufacturers' agent. Mr. Pettee was a member of the Masonic Fraternity and of the Highland Presbyterian Church.

He was married in 1874 at Ilion, N. Y. He leaves his widow, Mrs. Ida Owen Pettee, a daughter, Mrs Herbert F. Black, and a son, Robert Owen Pettee, of Oakmont, Pa.; also a sister, Mrs P. W. Skinner, of Washington, D. C.

ALFRED SANG.

Paris, France, September 6, 1876.

Antwerp, Belgium, October 2, 1914.

He was born in Paris of English parentage. His father was a well-known artist. He graduated from a leading French technical school. Shortly before coming to the United States he married Miss Sarah Spang, daughter of Norman B. Spang, of the family which founded the Spang-Chalfant Co. mills in Sharpsburg.

In 1900 Mr. Sang came to Pittsburgh, becoming a member of the Garland Corporation. Until 1908, when his family went to Europe, Mr. Sang's residence was in Sewickley. In June, 1909, he left Pittsburgh, going to Paris, thence to London. In London he formed the firm of Sang & Russell, also acting as confidential agent of the Garland Corporation.

While in Pittsburgh Mr. Sang was a member of the Engineers' Society of Western Pennsylvania, the American Society for Testing Materials, and of the Electro Chemical Society. He was also a member of the Union Club. Mr. Sang was an engineer, artist, musician and linguist, speaking French, German, Spanish, Italian, English and Russian. He was also known as a contributor to trade journals and as a student of psychology.

He leaves his widow and three children, Alfred, Elizabeth and Sarah, and a sister, Mrs. George Collins, formerly of this city, but now living in Idaho.

ABSTRACT OF MINUTES

FEBRUARY 1914—JANUARY 1915

ANNUAL MEETING

The Thirty-fourth Annual Meeting of the Engineers' Society of Western Pennsylvania was held in the Society rooms, Oliver Building, Pittsburgh, Tuesday, January 20, 1914, at 8:15 P. M., President Samuel A. Taylor presiding, 90 members and visitors being present.

The minutes of the last annual meeting held January 21, 1913, were read and approved.

The annual report of the Board of Direction which included the reports of the Standing and Special Committees, the Sections and the Treasurer, was read as follows:

REPORT OF THE BOARD OF DIRECTION

The Board of Direction of the Society held ten regular meetings and one special meeting during the past year, at which the routine of business of the Society was transacted.

During the year there were held nine regular meetings and the annual meeting of the Society. The average attendance was 177.

The average number participating in the discussion of papers was 9, the maximum attendance was 350 and the minimum 72.

At the close of the year the membership of the Society was as follows:

Honorary members	6
Members	979
Associate members	2
Associates	30
Juniors	87
Student Juniors	20
Total	1124

This is the largest membership in the history of the Society.

During the year there were:

Resignations	37
Removed by death	3
Dropped	25
Total	65
Accessions	128

The net increase in membership during the year is 70.

REPORT OF HOUSE COMMITTEE

To the Board of Direction, Engineers' Society of Western Pennsylvania:

On behalf of the House Committee, I have the following report to present:

In accordance with the By-Laws, an inventory of the effects of the Society has been made and the furnishings of the Society house kept in proper repair.

It is gratifying to note that the Society rooms are being used more and more by our members. Our chess players are coming in quite regularly during the noon hour, and there is always opportunity for a game. The Committee desire to recommend the purchase of two additional chess tables and sets of chess men similar to the equipment at present in the club room.

During the year, the auditorium has been used on 43 occasions, 21 times for Society meetings and 22 times for other organizations.

The Society rooms have been open every Saturday night throughout the year.

The members of this Committee believe that the matter of a permanent home for the Society should be in the minds of our members, and that the matter should be discussed periodically. When circumstances seem favorable, the project should go forward, and it is believed that in time it will be possible for the Society to be adequately housed in its own quarters.

Respectfully submitted,

JAMES O. HANDY, *Chairman.*

REPORT OF PUBLICATION COMMITTEE

To the Board of Direction, Engineers' Society of Western Pennsylvania:

The work of the Publication Committee during the past year has been along the same lines as those followed for several years past. Interesting subjects and competent speakers to present them have been sought both within and without the Society's membership. The Proceedings as printed show the results obtained. The report would be incomplete without acknowledging the Secretary's part in this work. He has not only assisted but has led, and we desire to express our appreciation of this fact. The attendance at the meetings has shown

that the subjects presented have met with the approval of the members, and it is hoped that all members will assist in securing papers on similar subjects for the coming year.

Respectfully submitted,

ALEX. L. HOERR, *Chairman.*

REPORT OF ENTERTAINMENT COMMITTEE

To the Board of Direction, Engineers' Society of Western Pennsylvania:

The Entertainment Committee presents the following report:

During the latter part of the year several inspection trips were made as follows:

On November 1st, a joint inspection trip with the Cleveland Engineering Society was made to The Pressed Steel Car Company's Works at McKees Rocks and to the plant of the Universal Portland Cement Company at Universal, Pa. The members of our Society met the special train carrying the members of the Cleveland Engineering Society at the McKees Rocks station of the P. & L. E. R. R., which transported the entire party directly to the Pressed Steel Company's Works. A very efficient corps of guides under the direction of Harvey Allen, Works Engineer, who had charge of the inspecting party, escorted the visitors through the Works. Leaving McKees Rocks, a sumptuous lunch was served through the courtesy of the officials of the Universal Portland Cement Company. A stop was made at 1:15 at the P. & L. E. R. R. Terminal Station in Pittsburgh to pick up members of the Society who were unable to join the party in the morning. Proceeding to Universal, the party was in charge of B. H. Rader, Eastern Manager for the Universal Portland Cement Company, and his assistants, W. M. Kinney and J. L. Nelson. At Universal the party was met by E. D. Barry, Supt. and R. L. Slocum, Asst. Supt. of Plant No. 5 of the Company, who, with a very capable corps of guides, escorted the visitors in groups through the entire works. Returning to Pittsburgh the members of the two Societies joined in a dinner at the Monongahela House at 6:00 o'clock, after which addresses were made by Samuel A. Taylor, President of our Society; E. H. Whitlock, Vice President of the Cleveland Engineering Society; E. P. Roberts and Willard Behan of the Cleveland Society; and Geo. H. Neilson and Harry J. Lewis of our own Society. The total attendance was 390, the Cleveland delegation numbering 130.

On November 29th, we visited the works of the Mesta Machine Co., where a large twin tandem compound reversing engine and a three-cylinder compound reversing engine were inspected. The details

of these engines presented many features of special interest. The attendance was about 250.

On December 13th, an inspection trip was made to the works of the Westinghouse Electric & Manufacturing Company to inspect a 6000 h.p. motor designed to drive a rail mill, and a 3000 h.p. motor designed to drive a 12 in. mill through direct connection and a 16 in. mill through a rope drive. The attendance was about 60.

Two smokers were held during the year; the first on March 8th at the Union Club, where we were entertained by J. W. Bengough of Toronto with a semi-humorous talk illustrated by crayon drawings made on the spot. Richard Hirsch made a very humorous address, bringing out the hobbies of a number of the members of the Society. The attendance was about 325.

The second smoker of the year was held on Oct. 25th at the Fort Pitt Hotel. Harry Lewis, Walther Riddle and others made brief addresses. The attendance was about 300.

A new departure in our Society life was made on November 28th, when a reception was given at the Rittenhouse, the evening being devoted to dancing and cards. This was a thoroughly enjoyable affair, and was most successful from every point of view. The ladies of the Society took great interest in it, and indeed the success of the evening's entertainment was entirely due to the splendid work of the several Committees organized by the ladies of the Society. The attendance was about 260.

It is believed by the members of the Committee that more attention should be paid to the social features in our Society life, and would earnestly recommend that frequent smokers be held and that two receptions similar to the one held at the Rittenhouse be given each year.

Respectfully submitted,

EDWIN H. HASLAM, *Chairman.*

REPORT OF FINANCE COMMITTEE

To the Board of Direction, Engineers' Society of Western Pennsylvania:

Your Committee made monthly audits of the books of the Secretary, and also of the financial statements prepared by him for the regular meetings of the Board of Direction. The books have been correctly kept and the statements properly show the financial transactions of the Society.

Respectfully submitted,

SAMUEL E. DUFF, *Chairman.*

REPORT OF MEMBERSHIP COMMITTEE

To the Board of Direction, Engineers' Society of Western Pennsylvania:

The Membership Committee desires to report the following accessions to membership in the Society during the past year:

Members	87
Associate Members	2
Associates	11
Juniors	19
Student Juniors	9
Total	128

The Junior membership of the Society now numbers 87 and it is believed that this grade of membership should be increased in order to extend our field of usefulness. It is hoped that during the coming year more of the advanced students in the engineering schools of the City will avail themselves of the privileges of the Student Junior grade of membership, and it is desired to bring this matter particularly to the heads of the Engineering Departments of the local engineering schools as such membership in the Society will prove of great benefit to the engineering students.

Respectfully submitted,

GEORGE H. BARBOUR, *Chairman.*

REPORT OF TREASURER

To the Board of Direction, Engineers' Society of Western Pennsylvania:

Your Treasurer takes pleasure in presenting the following statement of the finances of the Society for the year ending December 31st, 1913:

INVESTMENTS

Building Fund

One, $1000 Butler Water Company, 5 percent bond, No. 9, matures September 2, 1931	$1025.00

Permanent Fund

Two, $1000 Connellsville Water Company 5 percent bonds, Nos. 317-318, maturing October 1, 1930	2020.00
Two, $1000 Portsmouth, Berkley & Suffolk Water Company 5 percent bonds, Nos. 465-466, maturing Nov. 1, 1944	2000.00
Three, $1000 Jones & Laughlin Steel Company 5 percent bonds, Nos. 3020-3022, maturing May 1, 1931	2997.92
Total eight bonds	$8042.92

RECEIPTS		*EXPENDITURES*	
Dues 1914	$ 9.00	Administration	$ 4914.81
1913	7637.50	Entertainment	3020.06
1912	250.85	House	2926.68
1911	105.00	General Society	1014.55
1910	50.00	Mechanical Section	158.78
1909	18.75	Structural Section	143.73
Entrance Fees	950.00	Metallurgical and Mining Section	19.05
Advertising	2078.71	Committee on Engineering Education	24.00
Proceedings	355.41	Proceedings	2891.76
Rent of Auditorium	160.00	Advertising	135.23
Banquet Receipts	2708.50	Miscellaneous	28.50
Smoker Receipts	373.01		
Reception Receipts	187.00		
Interest	657.71		
Society Pins	62.50		
Miscellaneous	23.52		
	$15 627.46		$15 277.15

TOTAL ASSETS

	December 31*st*, 1912	*December* 31*st*, 1913
Bonds	$ 9052.92	$ 8042.92
Permanent Fund	1792.16	5606.48
Building Fund	574.89	586.37
General Fund	2723.64	310.20
	$14143.61	
Increase in Assets for 1913 over 1912	402.36	
	$14545.97	$14545.97

Respectfully submitted,

A. E. Frost, *Treasurer.*

REPORT OF MECHANICAL SECTION

To the Board of Direction, Engineers' Society of Western Pennsylvania:

Five regular meetings of the Mechanical Section of the Society were held in 1913 with an average attendance of 89, the maximum attendance was 100 at the April meeting and the minimum 74 at the December meeting. The average number participating in the discussion of papers was 8.

The papers presented were as follows:

February meeting: "The Technical Man and the Steel Works" by W. E. Snyder, Mechanical Engineer, American Steel & Wire Co.

April meeting: Discussion of "The Question of Specifications" was opened by T. D. Lynch, Research Engineer, Westinghouse Elec. & Mfg. Co.

June meeting: "Refractories in Modern Boiler Plants" by Kenneth Seaver, Chief Engineer of the Harbison-Walker Refractories Co.

October meeting: "The Decline of Oil Wells and Maintenance of Production" by L. G. Huntley, Geological Engineer, The Associated Geological Engineers, and "The Mud and Fluid Process applied to Dry Hole Cable Drilling" by J. A. Pollard, Petroleum Engineer, U. S. Bureau of Mines.

December meeting: "Selection of Electric Motors, Minimum Maintenance and Repairs" by James Dixon, Construction Engineer, Crocker-Wheeler Co., Ampere, N. J.

These papers were selected with the idea of presenting subjects of particular interest to the Mechanical Engineers in the Pittsburgh District. The adoption of this policy, which was recommended some time ago by the Board of Direction, has been fully justified during the past three years by the experience of the Mechanical Section.

Respectfully submitted,

George H. Neilson, *Chairman.*

REPORT OF STRUCTURAL SECTION

To the Board of Direction, Engineers' Society of Western Pennsylvania:

I beg to submit to you the following report of the work done by the Structural Section during the year 1913:

Five regular meetings were held, and at each of these meetings there was presented a paper. The papers in some instances were very freely discussed. The dates of the meetings and the papers presented are as follows:

January 7, 1913, a paper entitled "A Simple, Practical Method for Determining the Stresses in a Hingeless Elastic Arch Rib" was presented by T. J. Wilkerson, Division Engineer and Bridge Designer, Bureau of Construction, Department of Public Works. The attendance at this meeting was 59 and the number entering into the discussion of the paper was 3.

On March 4, 1913, a paper entitled "The Fire-proof Building, its Advantages and Weaknesses" was presented by H. W. Forster, Chief

Engineer, Independence Inspection Bureau, Philadelphia. The attendance at this meeting was 37 and the number entering into the discussion of the paper was 6.

On May 6, 1913, a paper entitled "The Historic Failures of Engineering Structures" was presented by Horace R. Thayer, Asst. Professor of Structural Design, Carnegie Institute of Technology. The attendance at this meeting was 101 and the number entering into the discussion of the paper was 8.

On September 9, 1913. a paper entitled "Composition Flooring" was presented by H. M. Hooker, District Manager of the Marbleoid Company. The attendance at this meeting was 57 and the number entering into the discussion of the paper was 8.

On November 4, 1913, a paper entitled "The Design of Linings for Mine Shafts" was presented by William Archie Weldin, Asst. Chief Engineer, Pittsburgh-Buffalo Company. The attendance at this meeting was 38 and the number entering into the discussion of the paper was 7.

The average attendance during the year was 58 and the average number entering into discussion of the papers was 7.

At the meeting held January 6, 1914, the following officers were selected for the ensuing year:

Chairman, William E. Mott.
Vice Chairman, George H. Danforth.
Directors, F. R. Dravo, N. S. Sprague, L. F. W. Hildner.

Respectfully submitted,

EDWARD GODFREY, *Chairman.*

REPORT OF TELLERS

To the Members of the Engineers' Society of Western Pennsylvania:

The ballots cast in the annual election were publicly canvassed at 12:00 o'clock noon, January 20th, 1914.

The vote being as follows:

For President.	Albert R. Raymer	228
For Vice President.	Samuel E. Duff	228
For Treasurer.	A. E. Frost	230
For Director.	George H. Neilson	228
For Director.	Fred Crabtree	228
Scattering.	....	3

Respectfully submitted,

C. M. MEANS,
B. F. GROAT,
L. C. STEELE,
Tellers.

These gentlemen were thereupon declared elected.

The President requested Thomas H. Johnson and James P. Leaf to escort President-elect Albert R. Raymer to the chair, who addressed the Society as follows:

Gentlemen, I appreciate the honor you have bestowed upon me. It is not necessary for me to say anything about the work of the Society, since you have heard the reports of the various committees. It is not necessary for me to make any predictions about the work for the coming year, as the Society is under such magnificent momentum that it will be very easy, with the continuance of your cooperation, to place the work on a plane still higher, possibly, than it has been in the past, provided we maintain the same rate of progress. I have had the pleasure of being connected with the Society for quite a number of years in various capacities, as a member of the Board of Direction for a number of years and as Chairman of some of the Committees, and it has been a great pleasure to me to give what little assistance it has been in my power for the welfare of the Society. I look to each of you for loyal support of the new officers, your assistance in contributing papers, your assistance in discussion, and, most of all, your assistance by attending the various meetings of the coming year. Again I thank you for this honor and hope it will be a successful year.

Mr. Chester B. Albree: I have been a member of this Society for so many years that I have forgotten when I joined, and it seems to me it is due to our present members to recognize that in the progress of this Society we have been wonderfully assisted by the efforts of a single man. Not that others have not done their duty, but this man has been especially delegated to look after us. I refer to Mr. Hiles, our Secretary. He has been in charge here now for over five years, and I wish to have passed tonight a vote of appreciation of Mr. Hiles' efforts. He has done as much as any man ever connected with this Society to make it go in every way, in its technical meetings, in its excursions and in its entertainment of foreign bodies which have been here, over and over again. And I move, Mr. President, that a vote of appreciation be extended to Mr. Hiles for his splendid efforts in the past for this Society.

President Raymer: It gives me great pleasure indeed to put a motion of this kind, because it appeals very strongly to me. I have been working with Mr. Hiles for a number of years, and I know the truth of every word Mr. Albree has expressed, and I am sure it will be heartily concurred in by all the Chairmen of the various Committees who have worked with him.

Mr. A. Stucki: It is appreciated not only by the Chairmen of the Sections and of the Committees, but it is appreciated by all of us, by every member coming here, and by visitors attending our meetings,

and every man who goes out of the Society rooms feels not only that he has got what he came for but got it in a pleasant way.

Mr. Samuel E. Duff: I would like to say that if we stayed here all night and talked about it we could not make a complete catalogue of the many useful activities of Mr. Hiles in this Society. As well as Mr. Stucki and Mr. Albree, I have been so connected with the Society lately that I have become very appreciative of that fact, and I want to add my humble tribute to his efforts.

Mr. S. A. Taylor: I think in a Society of this kind the larger part of it is the Secretary, and in the case of a number of Societies similarly situated the offices of the President and other officers are usually honorary positions, but the Secretary is the man who has to do the work. And I want to say that I concur heartily in what has been said.

Dr. A. E. Frost: I have followed the entire course of the history of the Society and have known the beginnings and now I know not the end, but the present, which I am sure is not the end of accomplishment. It gives me also great pleasure to second most heartily everything that has been said in regard to one who has been both co-worker and friend. It gives me great pleasure to second everything that has been said in regard to Mr. Hiles.

Mr. George H. Neilson: On behalf of the Entertainment Committee I would like to say that the success of the banquet last year was due entirely to Mr. Hiles' work, and the success we expect to have this year is along exactly the same lines; through Mr. Hiles' individual efforts and work we have been successful in getting Mr. A. H. Smith and also some others. I think this tribute is due to Mr. Hiles.

The motion was carried by unanimous vote.

President Raymer: Mr. Hiles, it gives me great pleasure to extend to you the unanimous thanks of the Society.

Mr. Elmer K. Hiles: This meeting has developed in a most unexpected manner and I feel very embarrassed. I appreciate deeply your kindly words and it is very pleasant to hear them. Our old Society has grown in many ways during the last few years and I am glad to have had my little opportunity to assist in its development. But the great factor in the success of the Society has been the loyal support and active interest of a large number of individual members, and lying behind this we should always remember that these things were made possible by that group of engineers, the founders of our Society, who laid the broad, comprehensive and enduring foundation on which we have been building. They were far-seeing, broad-minded men who early recognized the needs of the engineers of Western Pennsylvania, and founded a Society for the engineers of this district which will last for all time. It is well for us to recall these things to mind

on occasions like this in order that we may be quickened in our efforts to realize the high ideals of these men to whom we owe so much. I visit other cities once in a while on Society work and I frequently hear some fine things said of our old Society and the men who are in it, complimenting you on the things accomplished by the Society and recorded in our Proceedings. I am always greatly cheered on such occasions and prize more highly the privilege of an active connection with so old and dignified an organization which stands so high in the estimation of engineers residing in other communities. You have all been very kind to me and I appreciate it very much. Ever since I came into the office of Secretary of the Society there is one thing that I have always felt sure of, and that is that every man in the Society is my friend—this means very much to me. I am not much of a hand at making acknowledgement of such kind expressions which have been made in so friendly a spirit tonight, but I wish to thank Mr. Albree, Mr. Raymer, Mr. Stucki, Mr. Duff, Dr. Frost, President Taylor, Mr. Neilson and all of you for your cheering words.

No further business coming before the Society the retiring President, Samuel A. Taylor, addressed the Society on "The Advancement in Bituminous Coal Mining."

The meeting adjourned at 10:10 P. M.

ELMER K. HILES, *Secretary.*

STRUCTURAL SECTION

The annual meeting of the Structural Section of the Engineers' Society of Western Pennsylvania was held in the Society rooms, Oliver Building, Pittsburgh, Tuesday, January 6th, 1914, at 8:30 P. M., Chairman Edward Godfrey presiding, seventy members and visitors being present.

The minutes of the last annual meeting held January 7th, 1913, were read and approved.

The Nominating Committee presented the following report:

"To the Members of the Structural Section,
Engineers' Society of Western Pennsylvania.
Gentlemen:

Your Nominating Committee wish to suggest the following names for the officers of the Section for the ensuing year:

Chairman,	William E. Mott,
Vice Chairman,	Geo. H. Danforth,
Directors,	F. R. Dravo, N. S. Sprague, L. F. W. Hildner.

Respectfully submitted,

HARRY J. LEWIS,
E. W. PITTMAN,
SAMUEL E. DUFF."

No further nominations being made, the Secretary was requested to cast a unanimous ballot for the members named, who were thereupon declared elected.

On motion the annual meeting adjourned at 8:40 P. M.

The regular bi-monthly meeting of the Structural Section of the Engineers' Society of Western Pennsylvania was held in the Society rooms, Oliver Building, Tuesday, January 6th, 1914, at 8:30 P. M., Mr. N. S. Sprague presiding, 70 members and visitors being present.

The minutes of the last regular meeting held November 4th were read and approved.

No further business coming before the Section, the paper of the evening on "The Strength of Equipment for Handling Loads" was presented by Edward Godfrey, Structural Engineer, Robert W. Hunt & Co., Pittsburgh.

The ensuing discussion was participated in by John A. McCullough, Engr. Galvanizing Dept., National Tube Co., McKeesport; Willis Whited, Engr. of Bridges, State Highway Dept., Harrisburg, Pa.; Geo. W. Nichols, Engr., John Eichleay Jr. Co., Pittbsurgh; G. E. Flanagan, Mech. Engr., Heyl & Patterson, Pittsburgh; W. P. Flint, Engr., Westinghouse Mach. Co., East Pittsburgh, Pa.; P. E. Hunter, President, Independent Bridge Co., North Side, Pittsburgh; Harry Lewis, Cons. Engr., Pittsburgh, and Edward Godfrey.

The meeting adjourned at 10:45 P. M.

ELMER K. HILES, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society rooms, Oliver Building, Pittsburgh, Monday, January 12th, 1914, at 4:25 P. M., President S. A. Taylor presiding, Messrs. Raymer, Hawley, Duff, Snyder, Hoerr, Stucki, and the Secretary being present.

The minutes of the last regular meeting held December 5th were read and approved.

The applications of the following gentlemen having been regularly published to the Society pursuant to the action of the Board on December 5th, were duly elected to membership.

MEMBER

Arthur, Guy Browning
Douglass, Robt. M.
Gerwig, Homer Christian
Hardy, Geo.
Lombard, Eugene
McConway, William, Jr.
Smith, Herbert Paul

ASSOCIATE

Mason, J. R.
Schley, Charles
Swan, John W. H.

JUNIOR

Van Eman, Kenneth Walter

Applications for membership in the Society were received from the following gentlemen, and their names ordered published to the Society.

MEMBER

Parke, Frederic Huntington
Stout, Orin C.
Case, Geo. Wilkinson
Carter, Richard H.
Jackson, Wm. H.
Kalb, Warren Cornelius
McBroom, Herman P.
McCabe, Wm. Perry
Straub, Albert A.
Swarts, G. Taylor
Thomas, Wm. Arthur

ASSOCIATE

Peabody, Geo. L. Jr.
Clifford, Thos. C.

JUNIOR

Harton, Elliott Erskine
Lewis, Robt. Ash
Stattenfield, H. H.
Supplee, Chas. W.
Phillis, Wm. Avery
Wilson, Edgar Hamilton, Jr.

The report of the Secretary showing the financial condition of the Society at the close of business December 31st, having been previously audited by the Finance Committee, was approved.

The Secretary presented a letter from Elliott H. Whitlock, Chairman of the Publicity Committee, relative to publicity work in Engineering Societies. The matter was ordered referred to the Publication Committee.

The meeting adjourned at 5:40 P. M.

ELMER K. HILES, *Secretary.*

REGULAR MONTHLY MEETING

The 334th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Pittsburgh, Tuesday, February 17th, 1914, at 8:20 P. M., Vice President Samuel E. Duff presiding, 114 members and visitors being present.

The minutes of the last regular meeting were read and approved.

The Board of Direction reported the election of seven Members, one Associate Member, two Associates and one Junior; and the receipt of nineteen applications for membership.

No further business coming before the Society, the papers of the evening on "Operating Experiences with Steam Regenerators" were presented as follows:

Test of Steam Regenerators and Low Pressure Turbines by F. E. Leahy, Asst. Steam & Hyd. Engr., National Works, National Tube Co., McKeesport.

Specifications for Regenerators, by O. P. Hood, Chf. Mech. Engr., U. S. Bureau of Mines, Pittsburgh.

Test on an Experimental Steam Regenerator, by C. L. W. Trinks, Prof. of Mech. Engrg., Carnegie Institute of Technology.

The ensuing discussion was participated in by C. H. Smoot, Chief Engineer, Rateau Steam Regenerator Co., New York; John A. Hunter, Mech. Engr., Amer. Sheet & Tin Plate Co., Pittsburgh; J. A. McCulloch, Mech. Engr., National Tube Co., McKeesport; H. C. Siebert, Steam Engr., Duquesne Works, Carnegie Steel Co.; L. Lee, Chief Engr., Youngstown Sheet & Tube Co., Youngstown, O.; L. Battu, President Rateau Steam Regenerator Co., New York; F. E. Leahy and O. P. Hood.

The meeting adjourned at 11:10 P. M.

ELMER K. HILES,
Secretary

MECHANICAL SECTION

The annual meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Pittsburgh, Tuesday, Feb. 3, 1914 at 8:20 P. M.; Chairman Geo. H. Neilson, presiding, eighty members and visitors being present.

The minutes of the last annual meeting held Feb. 4, 1913 were read and approved.

The report of the nominating committee was presented as follows:

February 3, 1914.

To the Officers and Members of the Mechanical Section, Engineers' Society of Western Pennsylvania:

The committee appointed to nominate officers for the Section for the ensuing year offers the following nominees, covering the several offices in the Section for the year 1914.

Chairman................John A. Hunter
Vice Chairman........Stewart M. Marshall
Directors............ T. D. Lynch, J. A. McCulloch, Albert Kingsbury

Respectfully submitted,
ALEX. L. HOERR, *Chairman.*

On motion the Secretary was requested to cast a unanimous ballot for the gentlemen nominated who were thereupon elected.

The chairman requested Mr. J. A. McCulloch to take the chair since the Chairman-Elect, Mr. John A. Hunter, was out of the city.

No further business coming before the Section, the address of the retiring chairman: "Crucible Steel: Some Interesting Facts" was presented by Geo. H. Neilson.

The meeting adjourned at 9:25 P. M.

ELMER K. HILES,
Secretary

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society rooms, Oliver Building, Pittsburgh, Monday, February 16th, 1914, at 4:20 P. M., President A. R. Raymer presiding, Messrs. Hawley, Haslam, Handy, Neilson, and the Secretary being present.

The minutes of the last regular meeting held January 12th, were read and approved.

The applications of the following gentlemen having been regularly published to the Society pursuant to the action of the Board on January 12th, were duly elected to membership:

MEMBER

Carter, Richard H.	McCabe, William Perry
Case, George Wilkinson	Parke, Frederic Huntington
Jackson, William H.	Stout, Orin C.
Kalb, Warren Cornelius	Straub, Albert A.
McBroom, Herman P.	Swartz, G. Taylor

Thomas, William Arthur

ASSOCIATE

Clifford, Thos. C.	Peabody, George L. Jr.

JUNIOR

Harton, Elliott Erskine	Stattenfield, H. H.
Lewis, Robt. Ash	Supplee, Charles W.
Phillis, Wm. Avery	Wilson, Edgar Hamilton Jr.

Applications for membership in the Society were received from the following gentlemen, and their names ordered published to the Society:

Dean, Ellsworth	Riddle, Lawrence E.
Knesche, Joseph Albert	Smith, Walter Lynes
Luce, Wilson Ayres	Stalknecht, August Charles

A request for reinstatement in the Society was received from Clay Sprecher, Pittsburgh Mgr., The C. & G. Cooper Company, who joined the Society May 1905, resigned April 6, 1907. His name was ordered replaced on the Society Rolls.

The Secretary retired from the meeting while the matter of election of a Secretary for the ensuing year was considered. Elmer K. Hiles was re-elected Secretary of the Society.

The report of the Secretary showing the financial condition of the Society at the close of business January 1st, 1914 having been previously audited by the Finance Committee was approved.

The meeting adjourned at 5:25 P. M.

ELMER K. HILES,
Secretary

REGULAR MONTHLY MEETING

The 335th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Pittsburgh, Tuesday, March 17th, 1914, at 8:20 P. M., Vice President A. Stucki presiding, 83 members and visitors being present.

The minutes of the last regular meeting were read and approved.

The Board of Direction reported the election of six Members, and the receipt of eight applications for membership in the Society.

No further business coming before the Society, the paper of the evening on "Lighthouse Lenses" was presented by George A. Macbeth, President, Macbeth-Evans Glass Co., which was followed by a discussion of the optical theory entering into the design of lighthouse lenses by Harry S. Hower, Professor of Physics, Carnegie Institute of Technology.

ELMER K. HILES,
Secretary.

STRUCTURAL SECTION

The regular bi-monthly meeting of the Structural Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Tuesday, March 3rd, 1914, at 8:20 P. M., Chairman William E. Mott presiding, 82 members and visitors being present.

The minutes of the last regular meeting held January 6th, 1914 were read and approved.

No further business coming before the Section, the paper of the evening on "Mine Valuation" was presented by James R. Finlay, Consulting Mining Engineer, New York City.

The ensuing discussion was participated in by W. E. Fohl, Mining Engineer, Pittsburgh; George S. Rice, Chief Mining Engineer, U. S. Bureau of Mines; Robert Linton, Mining Engineer, Pittsburgh; Prof. S. L. Goodale, University of Pittsburgh; W. L. Affelder, General Supt., Bessemer Coke Co., and Mr. Finlay.

The meeting adjourned at 10:00 o'clock.

ELMER K. HILES,
Secretary.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society rooms, Oliver Building, Pittsburgh, Friday, March 6th, 1914, at 4:15 P. M., President A. R. Raymer presiding, Messrs. Hawley, Nelson, Stucki, Hoerr, and the Secretary being present.

The minutes of the last regular meeting held February 16th were read and approved.

The applications of the following gentlemen having been regularly published to the Society pursuant to the action of the Board on February 16th, were duly elected to membership:

MEMBER

Dean, Ellsworth	Riddle, L. E.
Knesche, J. A.	Smith, W. L.
Luce, W. A.	Stalknecht, A. C.

Applications for membership in the Society were received from the following gentlemen, and their names ordered published to the Society:

Berg, J. D.	Kortlandt, K. L.
Cresswell, G. M.	Mann, H. B.
Edge, Dexter	Murdoch, Harry
Henderson, David	Wysor, R. J.

The report of the Secretary showing the financial condition of the Society at the close of business February 28th, 1914, having been previously audited by the Finance Committee, was approved.

The Secretary presented a letter from the Executive Officers of the Sixth International Congress of Mining, Metallurgy, Engineering, and Practical Geology, extending an invitation to the Engineers' Society of Western Pennsylvania to participate officially in the proceedings of the Congress. After discussion, the Secretary was requested to acknowledge the invitation, advising that delegates would be named later.

The meeting adjourned at 4:50 P. M.

ELMER K. HILES,
Secretary.

REGULAR MONTHLY MEETING

The 336th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Pittsburgh, Tuesday, April 21, 1914, at 8:20 P. M., President A. R. Raymer presiding, 215 members and visitors being present.

The minutes of the last regular meeting were read and approved.

The Board of Direction reported the election of four Members, one Associate Member, one Associate and two Juniors to membership in the Society, and the receipt of fifteen applications for membership, together with two applications for transfer to higher grade of membership in the Society.

No further business coming before the Society, the paper of the evening on "Tests of a Large Reversing Engine and Rolling Mill" was read by Karl Nibecker, Steam Engineer, Youngstown Sheet and Tube Company, Youngstown, Ohio.

The ensuing discussion was participated in by Charles Fitzgerald, Jr., Asst. Steam Engr., Duquesne Works, Carnegie Steel Company; M. F. McConnell, Supt., Mingo Works, Carnegie Steel Company, Mingo Junction, Ohio; C. L. W. Trinks, Professor of Mechanical Engineering, Carnegie Institute of Technology; C. A. McCollum, Experimental Engineer, Homestead Works, Carnegie Steel Company; Julian Kennedy, Consulting Engineer, Pittsburgh; H. C. Siebert, Steam Engineer, Duquesne Works, Carnegie Steel Company; L. Iversen, Chief Engineer, Mesta Machine Company, Pittsburgh; F. E. Leahy, Asst. Steam Engineer, National Tube Company, McKeesport, Pa.; J. C. Hobbs, Steam Engineer, Duquesne Light Company, Pittsburgh; A. Stucki, Consulting Engineer, Pittsburgh; W. C. Coryell, Asst. Professor Steel Works Engrg., Carnegie Institute of Technology, and Mr. Nibecker.

The meeting adjourned at 10:45 P. M.

ELMER K. HILES, *Secretary.*

MECHANICAL SECTION

The regular bi-monthly meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Society rooms, Oliver Building, Pittsburgh, Monday, March 30, 1914, at 8:20 P. M., Chairman John A. Hunter presiding, 92 members and visitors being present.

The minutes of the last regular meeting held were read and approved.

No further business coming before the Section the paper of the evening on "Hydraulic Mining" was presented by Howard W. DuBois, Consulting Mining Engineer, Philadelphia.

The ensuing discussion was participated in by George S. Rice, Chief Mining Engr., U. S. Bureau of Mines, Pittsburgh; M. B. Spauld-

ing, Mgr., Crocker-Wheeler Co., Pittsburgh; Robert Linton, Consulting Mining Engr.; W. E. Mott, Prof., Civil Engineering, Carnegie Institute of Technology; S. L. Goodale, Prof., Mining Engineering, University of Pittsburgh; B. F. Groat, Hydraulic Engr., Aluminum Co. of America; A. Stucki, Consulting Engineer; W. L. Affelder, Gen. Supt., Bessemer Coke Co.; H. E. Cole, Chief Engr., Harris Pump & Supply Co.

The meeting adjourned at 10:40 P. M.

ELMER K. HILES, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society rooms, Oliver Building, Thursday, April 9th, at 4:10 P. M., President A. R. Raymer presiding, Messrs. Crabtree, Stucki, Duff, Hawley, Nielson, and the Secretary being present.

The minutes of the last regular meeting held March 6th were read and approved.

The applications of the following gentlemen having been regularly published to the Society pursuant to the action of the Board on March 6th were duly elected to membership:

MEMBER

Berg, John D.
Edge, Dexter
Mann, Harvey B.
Wysor, Rufus J.

ASSOCIATE MEMBER

Henderson, David

ASSOCIATE

Murdoch, Harry

JUNIOR

Cresswell, George M.
Kortlandt, Karl L.

Applications for membership in the Society were received from the following gentlemen, and their names ordered published to the Society:

Barker, Jesse K.
Bretland, Charles W.
Crawford, Loyal F.
Cunningham, James S.
Dole, Arthur L.
Gillis, Raymond T.
Harrington, Clinton O.
Holliday, Alexander H.
Isherwood, John, Jr.
Pickton, Charles F.
Schellentrager, Jacob H.
Snyder, William T.
Tweedy, A. Mellick
Weinberg, Benjamin B.
Schmitt, August J.

Applications for transfer to higher grade of membership were received from the following gentlemen, and their names ordered published to the Society:

Abbe, Walter, Jr.
Witte, Herman C.

A request for reinstatement to membership was received from David S. Beyer, Manager Accident Prevention Department, Massachussetts Employees Insurance Association, Boston, who joined the Society May, 1912 and resigned June, 1912. His name was ordered replaced on the Society rolls.

The report of the Secretary showing the financial condition of the Society at the close of business March 31st, 1914, having been previously audited by the Finance Committee, was approved.

The Secretary presented a letter from Philip R. Kellar, Secretary, National Drainage Congress, requesting this Society to appoint delegates to the Fourth Annual Meeting of the Congress to be held in Savannah, Ga., April 22-25, 1914.

The Secretary was requested to advise Mr. Charles K. Lawrence, Chief Engineer, Central of Georgia Railway, who resides in Savannah, of his appointment as a delegate, and to advise either John N. Chester or Morris Knowles of appointment as delegate; the latter being dependent upon which one attends the Congress.

The Secretary presented a letter from Flavel Schurthoff, Secretary, National Conference on City Planning, requesting the Engineers' Society of Western Pennsylvania to appoint delegates to the Conference to be held in Toronto May 25-27 inclusive.

The Secretary was requested to notify A. W. Crouch and John S. Fielding, of Toronto, of their appointment as delegates from the Society.

The meeting adjourned at 5:45 P. M.

ELMER K. HILES,
Secretary.

REGULAR MONTHLY MEETING

The 337th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Lecture Hall of the Carnegie Library, Wednesday, May 13th, 1914 at 8:15 P. M. President Albert R. Raymer presiding, 500 members and visitors being present.

The minutes of the last regular meeting held April 21st, were read and approved.

The Board of Direction reported the election of seven Members, two Associate Members, one Associate, four Juniors, and one Student-Junior, to membership in the Society, and the receipt of seven applications for membership.

No further business coming before the Society, the paper of the evening on "How the Ancients would have Controlled the Mississippi River and its Tributaries" was read by Sir William Willcocks, Consulting Engineer, Cairo, Egypt.

The meeting adjourned at 10:15 o'clock.

Elmer K. Hiles,
Secretary.

STRUCTURAL SECTION

The regular bi-monthly meeting of the Structural Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Tuesday, May 5, 1914 at 8:20 P. M.; Chairman William E. Mott, presiding, sixty members and visitors being present.

The minutes of the last regular meeting, held March 3rd, 1914 were read and approved.

No further business coming before the Section, the paper of the evening on "Theory and Practice in Writing Building Laws" was read by John A. Ferguson, Engineer, Bureau of Building Inspection, City of Pittsburgh.

The ensuing discussion was participated in by Richard Hirsch, Mech. Engr., H. K. Porter Co.; Edward Godfrey, Structural Engr., R. W. Hunt Co.; Virgil D. Allen, Bldg. Inspector, Cleveland, Ohio; J. J. Shuman, Inspection Engr., Jones & Laughlin Steel Co.; C. G. Dunnells, Architect; Sidney J. Williams, Bldg. Inspector, Industrial Commission of Wisconsin; Virgil G. Marini, Consulting Engineer, Cleveland, Ohio; R. E. Schmidt, Architect, Chicago, Ill.; C. H. Blackall, Architect, Boston, Mass.; and John A. Ferguson.

The meeting adjourned at 10:30 P. M.

Elmer K. Hiles,
Secretary.

METALLURGICAL AND MINING SECTION

The regular bi-monthly meeting of the Metallurgical & Mining Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Pittsburgh, Friday, May 29, 1914, at 8:20 P. M., Dr. John S. Unger presiding, 50 members and visitors being present.

The election of officers for the Section was proceeded with, the following officers being elected for the year 1914:

Chairman, John S. Unger
Vice Chairman, Geo. S. Rice

Directors

Frank S. Slocum	Wm. E. Fohl
S. A. Taylor	Cameron C. Smith
F. N. Speller	S. L. Goodale

The Chairman was requested to appoint a committee to prepare and present at the next meeting By-Laws to govern the work of the Section.

No further business coming before the Section, the paper of the evening on "Progressive Alteration of Coals of the Northern Appalachian Fields" was presented by Dr. David White, Chief Geologist, U. S. Geological Survey, Washington, D. C.

The meeting adjourned at 10:30 P. M.

Elmer K. Hiles, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Friday, May 8, at 4:10 P. M. Vice President A. Stucki presiding, Messrs. Snyder, Duff, Taylor, Nielson, Hoerr, and the Secretary being present.

The minutes of the last regular meeting held April 9th were read and approved.

The application of the following gentlemen having been regularly published to the Society pursuant to the action of the Board on April 9th, were duly elected to membership:

MEMBER

Bretland, Charles W.	Harrington, Clinton O.
Crawford, Loyal F.	Pickton, Charles F.
Cunningham, James S.	Snyder, William T.

Tweedy, A. Mellick

ASSOCIATE MEMBER

Dole, Arthur L.	Holliday, Alexander H.

ASSOCIATE

Barker, Jesse K.

JUNIOR

Isherwood, John, Jr.	Schmitt, August J.
Schellentrager, Jacob H.	Weinberg, Benjamin B.

STUDENT JUNIOR

Gillis, Raymond T.

Requests for transfer to higher grade of membership in the Society were granted as follows:

Walter C. Abbe, Jr., was transferred from the Junior to the grade of Member.

Herman C. Witte was transferred from the Student Junior to the grade of Junior.

Requests for reinstatement to membership in the Society were received from: D. H. Chester, Vice Pres., Alberger Pump & Condenser Co., who joined the Society February 21, 1899, and J. F. Johnson, Engineer, Pittsburgh Plate Glass Co., who joined the Society in June 1904. Their names were accordingly ordered replaced on the Society rolls.

Applications for membership in the Society were received from the following gentlemen, and their names ordered published to the Society:

Barnsley, George T.	Iversen, Lorenz
Chandler, Willard P., Jr.	Koch, Carleton S.
Cunningham, John J.	Reinhardt, Gustav A.
Siebert, Hermann	

The report of the Secretary showing the financial condition of the Society at the close of business April 30th, 1914, having been previously audited by the Finance Committee, was approved.

The Secretary read the following letter from the family of our lamented Past President, Thomas H. Johnson:

"Engineers' Society of Western Pennsylvania,
Pittsburgh.

Dear Sirs:

My mother, brother, sister and myself desire to express to the members of the Society our very deep appreciation of its sincere sympathy to us, the family and loved ones of your fellow member, Mr. Thomas H. Johnson.

We know full well the honor you bestowed was all for him we loved, but we certainly appreciate it none the less, but rather ten fold more.

We thank you most gratefully for the wonderful basket of American Beauty roses which came as a final tribute to your Past President and my Father.

Assuring the members that we shall always have in our hearts a warm spot for the Engineers' Society of Western Pennsylvania, I am

Very sincerely,

April 23rd, 1914. Bessie D. Johnson."

The meeting adjourned at 5:30 P. M.

ELMER K. HILES, *Secretary.*

REGULAR MONTHLY MEETING.

The 338th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Pittsburgh, Tuesday, June 16, 1914, at 8:15 P. M., President A. R. Raymer presiding, 110 members and visitors being present.

Minutes of the last regular meeting held May 13, 1914, were read and approved.

The Board of Direction reported the election of four members, one Associate member, one Junior and one Student Junior to membership in the Society and the receipt of three applications for membership.

No further business coming before the Society the paper of the evening on "Air in Jet Condensers" was presented by C. L. W. Trinks, Professor of Mechanical Engineering, Carnegie Institute of Technology.

The ensuing discussion was participated in by Karl Nibecker, Steam Engr., Youngstown Sheet & Tube Co.; W. E. Snyder, Mech. Engr., American Steel & Wire Co.; A. L. Hoerr, Steam & Hydr. Engr., National Tube Co.; Nathan Owitz, Engr., Wheeling Engineering & Condenser Co.; Mr. J. B. Shatzer, Engineer, Schutte & Koerting Co.; R. M. Rush, Dist. Mgr., Kerr Steam Turbine Co.; and Prof. C. L. W. Trinks.

The meeting adjourned at 10:40 P. M.

Elmer K. Hiles,
Secretary.

MECHANICAL SECTION.

The regular bi-monthly meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Pittsburgh, at 8:30 P. M., Chairman John A. Hunter presiding, 86 members and visitors being present.

The minutes of the last regular meeting held March 30th, 1914, were read and approved.

No further business coming before the Section, the paper of the evening on "Principles and Details Involved in Moving Large Structures" was presented by George W. Nichols, Engineer, John Eichleay Jr. Co., Pittsburgh.

The ensuing discussion was participated in by A. Stucki, Cons. Engineer; H. R. Thayer, Professor of Structural Engineering, Carnegie Institute of Technology; Emil Banenhauer, John Eichleay Jr. Co.; Hermann Laub, Cons. Engineer; T. J. Wilkerson, Div. Engr., Bureau of Bridges, City of Pittsburgh; and George W. Nichols.

The meeting adjourned at 10:25 P. M.

Elmer K. Hiles,
Secretary.

BOARD OF DIRECTION.

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Monday, June 1st, at 4:10 P. M., President A. R. Raymer presiding; Messrs. Crabtree, Stucki, Duff, Hawley, Snyder, Taylor and the Secretary being present.

The minutes of the last regular meeting held May 8th were read and approved.

The applications of the following gentlemen have been regularly published to the Society, pursuant to the action of the Board on April 9th were duly elected to membership:

MEMBER.

Iverson, Lorenz
Koch, Carleton S.
Reinhardt, Gustav A.
Siebert, Hermann

ASSOCIATE MEMBER.

Chandler, Willard P.

JUNIOR.

Barnsley, George T. Jr.

STUDENT JUNIOR.

Cunningham, John J.

Applications for membership were received from the following gentlemen and their names ordered published to the Society:

Sherman, Max C.
Snelling, Walter O.
Walton, M. R.

A report for the House Committee was presented by W. C. Hawley, Chairman, recommending that the Secretary be authorized to purchase ten or fifteen additional book-cases and also to have a number of chairs in the Auditorium reseated before the coming season.

An informal report of the work of the Committee on Engineering Education was presented by Samuel E. Duff. The Committee was thereupon authorized to proceed with making awards in the competition just closed and to advise the various schools interested that the Society will continue the competition during the coming year, presenting problems in the fields of Civil, Mechanical and Electrical Engineering and other fields if the Committee deems it advisable. The Committee were also authorized to extend the list of schools to be invited to participate in the competition.

The meeting adjourned at 5:30 P. M.

ELMER K. HILES,
Secretary.

SPECIAL MEETING

A special meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Pittsburgh, Monday, October 12, 1914, at 8:20 P. M., President Albert R. Raymer presiding, 99 members and visitors being present.

The reading of the minutes of the previous meeting was dispensed with.

President Raymer addressed the meeting stating that the meeting was called to discuss the subject as to whether it was desirable to require engineers to take out a license to practice and to discuss the provisions of a proposed law, copies of which had been mailed to members of the Society. Mr. Raymer further stated that a public hearing would be held in the Society's Auditorium by the Engineers' Commission on Thursday, October 15th at 10:00 A. M. and 2:00 P. M.

The Secretary was requested to read the provisions of the proposed bill.

President Raymer requested Mr. S. A. Taylor, a member of the Engineers' Commission, to present the work of the Commission before the meeting.

The ensuing discussion was participated in by Messrs. E. C. Brown, Geo. H. Barbour, W. W. Macfarren, Edward Godfrey, Henry D. James, John A. Ferguson, Thos. R. Cook, Robt. Linton, —— Eaton, Richard Hirsch, Wm. E. Mott, Albert Kingsbury, J. J. Shuman, —— Joseph, G. E. Flanagan, Louis P. Blum, Elmer K. Hiles, A. Stucki and W. A. Thomas.

The following motion was made and seconded:

That it is the sense of this meeting that it is not considered advisable or necessary to license engineers in this State.

After discussion this motion was passed practically unanimously, there being one dissenting vote.

The meeting adjourned at 10:35 P. M.

Elmer K. Hiles,
Secretary.

STRUCTURAL SECTION

September 29th, 1914

The regular bi-monthly meeting of the Structural Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Tuesday, Sept. 29th, 1914 at 8:20 P. M., Chairman Wm. E. Mott presiding, 60 members and visitors being present.

The minutes of the last regular meeting held May 5, 1914 were read and approved.

No further business coming before the Section the paper of the evening on "Constructive Features of the North Side Reservoir of the Water Works of the City of Pittsburgh" by Messrs. E. E. Lanpher and John S. Cole was read by Mr. Lanpher.

The ensuing discussion was participated in by Mr. Louis P. Blum, Civil Engineer; Mr. J. M. T. Rice, Civil Engineer; Mr. John A. Ferguson, Engr., Bureau of Building Inspection; Mr. H. H. Rankin, Civil Engineer; Mr. S. S. Fuller, Supt. Construction J. F. Casey Contracting Co., and Mr. Lanpher.

The meeting adjourned at 10:15 P. M.

Elmer K. Hiles,
Secretary.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Thursday, Sept. 10th at 4:00 P. M., President A. R. Raymer presiding; Messrs. Haslam, Duff, Stucki, Nielson, Taylor, Hoerr, and the Secretary being present.

The minutes of the last regular meeting held June 1st were read and approved.

The applications of the following gentlemen having been regularly published to the Society, pursuant to the action of the Board on June 1st, were duly elected.

MEMBERS

Snelling, W. O. Walton, M. R.

JUNIORS

Sherman, M. C.

A request was received from Theodore H. Schoepf for reinstatement in the Society. The Secretary was authorized to replace Mr. Schoepf's name on the Society rolls.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. The assignment to the various grades of membership is as follows:

ASSOCIATE MEMBER

Weaver, George H.

ASSOCIATE

Marks, H. E.

JUNIORS

Sheldon, Wm. J. Smith, Rupert V.
Voelker, Aloys A.

The report of the Secretary showing the financial condition of the Society at the close of business July 31st, having been previously audited by the Finance Committee, was approved.

The Secretary read a letter from Chas. Warren Hunt, Secy. of the American Society of Civil Engineers, including a series of resolutions adopted by the Board of Direction of that Society upon the death of Alfred Noble. The letter further advises that the American Society of Civil Engineers are initiating a plan for the erection of a permanent memorial to Alfred Noble, to be erected, probably, in the City of Washington. A committee has been appointed, consisting of

Onward Bates, Chicago, Ill., Chairman
Robert Moore, St. Louis, Mo.
Samuel Rea, Philadelphia, Pa.
Samuel H. Hedges, Seattle, Wash.
F. H. Newell, Washington, D. C.
Charles Warren Hunt, New York City, Secretary.

The letter states that "The Committee desires to enlist your present sympathy in the movement and your future aid in carrying it out by bringing it to the attention of the members of your organization whenever the details have been so far worked out that they may be laid before you." The Secretary was duly authorized to reply further to Mr. Hunt, expressing the sympathy of the individual members of the Board with this movement and advising that when the Committee have the details worked out, we will be glad to assist in bringing the matter to the attention of the members of the Society.

Mr. Samuel A. Taylor, a member of the Commission appointed by Gov. Tener to examine into the advisability and report to him regarding the matter of licensing engineers of all descriptions throughout the State of Pennsylvania, introduced the matter of the proposed law and advised that the Commission had drawn up a tentative form for the law for presentation to the Governor with its report, but desired, before presentation, to hold a public hearing in Philadelphia, Harrisburg and Pittsburgh, prior to presenting a report to the Governor. Mr. Taylor further advised that the Commission desired to hold a public hearing in Pittsburgh in the rooms of the Engineers' Society, which request was granted and that the Commission would supply Mr. Taylor with about 2500 copies of the proposed law for distribution to engineers in the Pittsburgh District.

After discussion, Mr. Taylor was requested to advise the Commission that the Board of Direction take pleasure in extending to them

the use of the Society Rooms for public hearing and also to advise the Commission that in view of the non-receipt of the copies of the proposed law, that the Board believes the date tentatively set for the hearing in Pittsburgh, Sept. 30th, to be an impossible one, in view of the time necessary to get the copies of the proposed law into the hands of the engineers of the district and to hold a special meeting of the Society for consideration of the matter prior to Sept. 30th. The suggestion was made that the hearing in Pittsburgh be deferred until a date about thirty days after the receipt of the copies of the proposed law.

The Secretary was authorized to mail the copies of the proposed law to the members of the Society and other engineers in the district, upon receiving them from Mr. Taylor.

The meeting adjourned at 5:10 P. M.

ELMER K. HILES,
Secretary.

REGULAR MONTHLY MEETING

The 339th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Pittsburgh, Tuesday, Oct. 20, 1914, at 8:25 P. M., President A. R. Raymer presiding, 33 members and visitors being present.

The minutes of the last regular meeting held June 16, 1914 and of the special meeting of the Society held Oct. 12, 1914, were read and approved.

The Board of Direction recorded the election of one associate member, one associate and three juniors to membership in the Society and the receipt of fourteen applications for membership.

No further business coming before the Society, the paper of the evening on "Railway Classification Yard Lighting" was presented by D. P. Morrison, Electrical Engineer, Pittsburgh and Lake Erie R. R.

The ensuing discussion was participated in by A. Stucki, Cons. Engineer; H. F. Prichard, Engr., American Bridge Co.; Samuel E. Duff, Consulting Engineer; W. C. Copeley, T. M., Middle Div. Penna. R. R.; S. G. Hibben, Illg. Engr., Macbeth Evans Glass Co.; H. Kirschberg, Illg. Engineer; W. D. Smoot, Ft. Wayne Div. Penna. Lines; A. C. Cotton, Engr., Motive Power, Penna. R. R., and D. P. Morrison.

The meeting adjourned at 10:40 P. M.

ELMER K. HILES,
Secretary.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Tuesday, Oct. 20, at 4:10 P. M., President A. R. Raymer presiding; Messrs. Duff, Stucki, Hoerr, Neilson and the Secretary being present.

The minutes of the last regular meeting held Sept. 10th were read and approved.

Applications of the following gentlemen having been published to the Society pursuant to the action of the Board on Sept. 10th, were duly elected to membership.

ASSOCIATE MEMBER

Weaver, George H.

ASSOCIATE

Marks, Herbert Earle

JUNIOR

Smith, Rupert V. Sheldon, William J.
Voelker, Aloys A.

Applications for membership were received from the following gentlemen and their names ordered published to the Society.

MEMBER

Bracken, Michael Joseph
Bryan, James
Coryell, William Clayton
Neely, William Reed
Pendergrass, Robert Allen

ASSOCIATE MEMBER

Kneass, Jr. Strickland
Norris, Edward W.
Roberts, Milnor
Schell, William Franklin
Taylor, Harold Alexander
Vauclain, Andrew Constant

JUNIOR

Benson, Frank Robert
Hislop, Will

STUDENT JUNIOR

Lovejoy, Francis Fleming

The Secretary announced the death of the following members of the Society:

Fawell, Joseph	Joined March 1899
Helander, A. H.	Joined January 1909
Sang, Alfred	Joined January 1907
Boileau, J. W.	Joined July 1907

The report of the Secretary showing the financial condition of the Society at the close of business August 31st, having been previously audited by the Finance Committee, was approved.

The Secretary presented a letter from Frederic H. Mason, Secretary of the Detroit Engineering Society, requesting the exchange of library and house privileges. The Secretary was requested to advise Mr. Mason that we will comply with his request.

The Secretary read a letter from Louis P. Blum referring to a recommendation made to the Board about eighteen months ago that a standard of measurement be established in the City of Pittsburgh. Mr. Blum calls attention to the report of a Committee of the Western Society of Engineers published in the September number of the journal of that Society, giving the details of the installation of a 100 ft. standard measure in the new county building of Chicago, under the supervision of a Committee of the Western Society of Engineers. In this letter, Mr. Blum again drew the Board's attention to the desirability of our Society making active efforts to secure the installation of a 100 ft. standard measure in the new city-county building about to be erected in Pittsburgh.

After discussion, the President was authorized to appoint a committee to examine into the possibilities in connection with the establishment of a standard of measure in the City of Pittsburgh. The President appointed the following committee:

Louis P. Blum, Chairman   Robert Swan   Jas. G. Chalfant.

The meeting adjourned at 5:20 P. M.

ELMER K. HILES, *Secretary.*

REGULAR MONTHLY MEETING

The 340th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Pittsburgh, Tuesday, Nov. 24, 1914 at 8:15 P. M., President A. R. Raymer presiding, 194 members and visitors being present.

The minutes of the last regular meeting held Oct. 20th, 1914 were read and approved.

The Board of Direction reported the election of five members, six associate members, two juniors, and one student junior to membership in the Society and the receipt of six applications for membership.

No further business coming before the Society, the paper of the evening on "The Magnolia Cut-Off Improvement on the Baltimore and Ohio Railroad" was read by Arthur W. Thompson, 3rd Vice President and Chief Operating Official of the B. & O. R. R., Baltimore, Md.

Mr. George S. Davison moved that a vote of thanks of the Society be tendered Mr. Thompson, which motion, after being seconded, was carried unanimously.

The meeting adjourned at 10:40 P. M.

ELMER K. HILES,
Secretary.

MECHANICAL SECTION

The regular bi-monthly meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Pittsburgh, on Monday, November 9, at 8:00 P. M., Chairman John A. Hunter, presiding; 46 members and visitors being present.

The minutes of the last regular meeting held June 2nd, 1914 were read and approved.

No further business coming before the Section, the paper of the evening on "Steam Turbine Mill Drive" was presented by John D. Berg, Vice President, Dravo-Doyle Company, Pittsburgh.

The ensuing discussion was participated in by:

F. E. Leahy, Asst. Steam & Hydr. Engr., National Tube Co., McKeesport, Pa.; Joseph Breslove, Sales Agent, Allis Chalmers Mfg. Co., Pittsburgh; A. L. Ahrens, Westinghouse Elec. & Mfg. Co., East Pittsburg, Pa.; Lloyd Jones, Asst. Chf. Engr., United Engineering & Fdry. Co., Pittsburgh; W. T. Chandler, Jr., Steam Engr., Clairton Works, Carnegie Steel Co., Clairton, Pa.; H. C. Cronemeyer, Eff. Engr., Jones & Laughlin Steel Co., Woodlawn, Pa.; J. A. Hunter, Mech. Engr.,

American Sheet & Tin Plate Co., Pittsburgh; J. S. Albert, Resident Engr., Southwark Fdry. & Mach. Co., Pittsburgh, and Mr. J. D. Berg.

The meeting adjourned at 10:30 P. M.

Elmer K. Hiles,
Secretary.

STRUCTURAL SECTION

The regular bi-monthly meeting of the Structural Section of the Engineers' Society of Western Pennsylvania, was held in the Society Rooms, Oliver Building, Monday, November 2, 1914, at 8:20 P. M., Chairman William E. Mott presiding, 94 members and visitors being present.

The minutes of the last regular meeting held September 29th, 1914, were read and approved.

No further business coming before the Section, the paper of the evening on "The Construction Features of the North Side Reservoir of the Water Works of the City of Pittsburgh" by Messrs. E. E. Lanpher and John S. Cole was read by Mr. Lanpher. The ensuing discussion was participated in by:

Samuel E. Duff, Consulting Engineer, Pittsburgh; W. C. Coffin, Structural Engr., Jones & Laughlin Steel Co., Pittsburgh; Arch McKinley, Engr., McClintic Marshall Co., Rankin, Pa.; E. W. Pittman, Mgr., McClintic Marshall Co., Rankin, Pa.; Harry J. Lewis, Consulting Engineer, Pittsburgh; P. E. Hunter, Pres. Independent Bridge Co., Pittsburgh, and R. A. Pendergrass.

The meeting adjourned at 10:35 P. M.

Elmer K. Hiles,
Secretary.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers Society of Western Pennsylvania met in the Society Rooms, Oliver Building, Pittsburgh, Monday, November 2, 1914, at 4:10 P. M., President A. R. Raymer presiding; Messrs. Neilson, Taylor, Duff, Stucki, Hoerr, Hawley, Crabtree and the Secretary being present.

The minutes of the last regular monthly meeting held October 20, 1914, were read and approved.

Applications of the following gentlemen having been published to the Society pursuant to the action of the Board on October 20th, were duly elected to membership:

MEMBER

Bracken, Michael Joseph	Coryell, William Clayton
Bryan, James	Neely, William Reed

Pendergrass, Robert Allen

ASSOCIATE MEMBER

Kneass, Strickland, Jr.
Norris, Edward W.
Roberts, Milnor
Schell, William Franklin
Taylor, Harold Alexander
Vauclain, Andrew Constant

JUNIOR

Benson, Frank Robert
Hislop, Will

STUDENT JUNIOR

Lovejoy, Francis Fleming

Applications for membership in the Society were received from the following gentlemen and their names ordered published to the Society.

MEMBER

Harbaugh, Ross Anderson
Taylor, Charles Francis

ASSOCIATE MEMBER

Pinkham, Frank L.

JUNIOR

Lose, James Edson
McGill, Arthur Harkins
Rabling, Harold

The report of the Secretary showing the financial condition of the Society at the close of business Sept. 30th. having been previously audited by the Finance Committee was approved.

The following report of the Nominating Committee was presented by George H. Neilson, Chairman:

To the President and Board of Direction,

Engineers' Society of Western Pennsylvania.

Gentlemen:

The Nominating Committee met on Thursday evening, Oct. 29th, the entire Nominating Committee being present with the exception of Mr. Fohl:

The following gentlemen were nominated:

Mr. A. Stucki, President
Mr. Alex. Hoerr, Vice President
Dr. A. E. Frost, Treasurer
Mr. John Unger } Board of Direction
Mr. William Hoopes } Board of Direction

Yours truly,

NOMINATING COMMITTEE

George H. Neilson, *Chairman.*
Robert A. Cummings,
William A. Bole,
George W. Hutchinson.

Mr. S. A. Taylor introduced the matter of the establishment of a true meridian in Pittsburgh and after discussion, it was referred to the Committee on Standards of which Mr. Louis P. Blum is chairman.

The meeting adjourned at 4:57 P. M.

ELMER K. HILES,
Secretary.

REGULAR MONTHLY MEETING

The 341st regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Pittsburgh, Tuesday, Dec. 15th, 1914, at 8:25 P. M., Vice President A. Stucki presiding, 176 members and visitors being present.

The minutes of the last regular meeting held Nov. 24th, 1914, were read and approved.

The Board of Direction reported the election of two members and one associate and three juniors to membership in the Society; reinstatement of one former member and the receipt of five applications for membership.

No further business coming before the Society, the paper of the evening on "Possibilities in Technical Photography" was read by Frederick Henius.

The meeting adjourned at 10:45 P. M.

ELMER K. HILES,
Secretary.

MECHANICAL SECTION

The regular bi-monthly meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Pittsburgh, on Monday evening, Dec. 1st, at 8:15 P. M., Chairman John A. Hunter presiding, 153 members and visitors being present.

No further business coming before the Section, the paper of the evening on "Recent Developments in the Heat Treatment of Gearing" by W. H. Phillips, Metallurgist of the R. D. Nuttall Co., was read by T. D. Lynch in the absence of Mr. Phillips, who was seriously ill.

The ensuing discussion was participated in by Messrs. A. Stucki, G. F. Hinken, W. L. Allen, S. M. Rodgers, G. M. Eaton, James O. Handy, S. A. Grayson, R. A. McDonald, J. S. Unger, W. R. Wigley, H. P. Tiemann and T. D. Lynch.

The meeting adjourned at 10:45 P. M.

ELMER K. HILES,
Secretary.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Pittsburgh, Monday, Dec. 7, 1914, at 4:15 P. M., President A. R. Raymer presiding; Messrs. Neilson, Duff, Hawley, Crabtree, Stucki, Frost and the Secretary being present.

The minutes of the last regular meeting held Nov. 2, 1914, were read and approved.

Applications of the following gentlemen having been published to the Society pursuant to the action of the Board on Oct. 20th, were duly elected to membership:

MEMBER

Harbaugh, Ross Anderson — Taylor, Charles Francis

ASSOCIATE MEMBER

Pinkham, Frank L.

JUNIORS

Lose, James Edson — McGill, Arthur Harkins

Rabling, Harold

Applications for membership in the Society were received from the following gentlemen and their names ordered published to the Society:

MEMBER

Bate, Harley A. — Neal, Albert Durant

Davis, William Arthur — Williams, Homer D.

JUNIOR

Heath, John Russell

A request for reinstatement to membership in the Society was received from Reinhardt Daae, who joined the Society Sept., 1902, and resigned March, 1904. The Secretary was authorized to replace Mr. Daae's name on the society rolls.

The report of the Secretary showing the financial condition of the Society at the close of business Oct. 31st having been previously audited by the Finance Committee was approved.

The Secretary reported the death of J. H. Thompson, who joined the Society Jan., 1903, and died Mar. 12, 1913.

The Secretary introduced the matter of the appointment of a committee on Standardizing Tests for Reversing Engines and Rolling Mills. After discussion, the President of the Society was authorized to appoint such a committee.

The Board of Direction finally passed upon the eligibility of all nominees as presented in the report of the Nominating Committee in accordance with the requirements of the By-Laws.

The meeting adjourned at 5:07 P. M.

ELMER K. HILES,
Secretary.

LIST OF PERIODICALS

ON THE TABLES IN THE READING ROOM OF THE SOCIETY

American Engineer.
American Society of Civil Engineers, Proceedings.
American Society of Mechanical Engineers, Proceedings.
American Water Works Association, Bulletin.
American Railway Engineering and Maintenance of Way Association, Bulletin.
Appleton's Magazine.
Analyst, The.
Annales de L'Association des Ingenieurs de Grand.
Annaes Scientificos de Academia Polytechnia Porto.
Anales de la Sociedad Cientifica 'Argentina.

Bi-Monthly Bulletin of Amer. Institute of Mining Eng.
Blast Furnace and Steel Plant.
Building Management.

Canadian Electrical News.
Cassier's Magazine.
Chamber of Mines, Monthly Journal of the
Chemical News.
Coal.
Coal Trade Bulletin.
Cold Storage and Ice Trade Journal.
Compressed Air.
Concrete.
Contractor The.
Cornell Civil Engineer.

Electric Journal.
Electric Railway Journal.
Electrical Review.
Electrical World.
Energy.
Engineering.
Engineering Magazine.
Engineering & Mining Journal.
Engineering News.
Engineering Record.
Engineering Review.
Engineering—Contracting.
Engineers' Club of Philadelphia Proceedings.
Engineering Journal, Canada
Engineering Digest.

Forum.
Foundry.

Gas Industry.

Harvard Engineering Journal.
Heating & Ventilating Magazine.

Illuminating Engineer.
Industry.
Industrial Engineering.
Industrial Magazine.
Industrial World.
Insurance Engineering.
Iron Age.
Iron Trade Review.

Journal of the American Society of Naval Engineers.
Journal of the Association of Engineering Societies.
Journal of the Franklin Institute.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Journal of the U. S. Artillery.
Journal of the Western Society of Engineers.

Les Mois Scientifique et Industrial.
Leslie's Weekly.
Locomotive.

Maschinen Kronstrukteur.
Mechanical World.
Metallurgical & Chemical Engineering.
Mexican Mining Journal The.
Mines & Minerals.
Monthly Journal of the Chamber of Mines.
Municipal Engineering.

National Engineer.
Natural Gas Journal.
Official Gazette U. S. Patent Office (Wash.)
Official Journal, Patents, (London).
Ores and Metals.
Outlook.

Physical Review.
Proceedings of the Engineering Association of the South.
Power.
Practical Engineer.
Proceedings of the Amer. Institute of Electrical Engineers.
Proceedings of the Academy of Natural Science.
Progressive Age.

Railway & Engineering Review.
Railway Age Gazette.
Railway Engineering.
Review of Reviews.
Revista de Construciones Y Agrimensura.
Revista de Obras Publicas E Minas.
Revue de L'Igenieur et Index Technique.

Scientific American.
School of Mines Quarterly.
Scientific American Supplement.
Scribner's Magazine.
Sibley Journal of Engineering.
Society of Chemical Industry.
St. Louis Railway Club.

Technical Index.
Technical Literature.
Technologist.
Technology Quarterly.
Technology Review.
Teknisk Tidskrt.
Transactions of the Liverpool, Eng. Society.

University of Illinois Bulletin.

Western Electrician.
Western Railway Club.

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Proceedings of

The Engineers' Society

of

Western Pennsylvania

Vol. 30 January, 1915 No. 10

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

INCORPORATED 1880

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PROCEEDINGS OF THE

Engineers' Society of Western Pennsylvania

INCORPORATED 1880

Edited by the Secretary under the direction of the Publication Committee
Published Monthly except August and September

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Proceedings of

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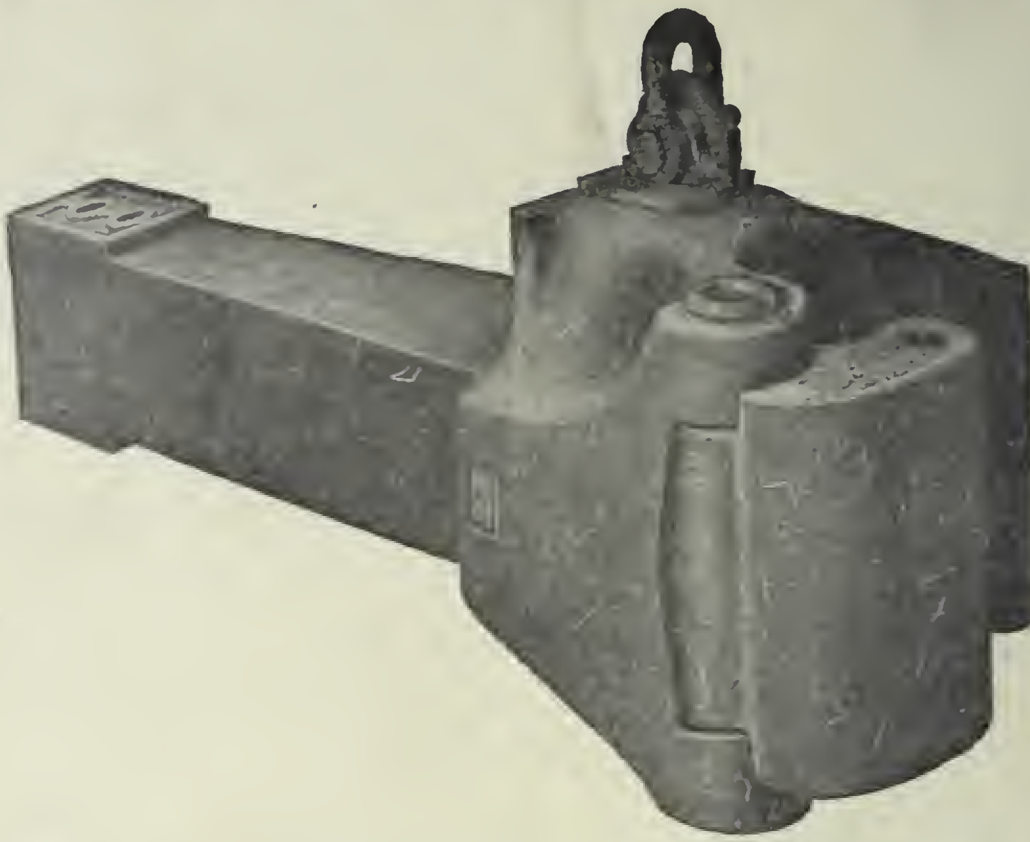
THE PENN COUPLER



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This coupler has the features of a "Lock-Set," a "Lock-to-the-Lock" and a "Knuckle-Opener," and complies fully with all the requirements and recommendations of the M. C. B. Association and the Safety Appliance Law.

Lock - Set. Lock setting is accomplished by the locking block when raised to the uncoupling position, resting on a seat on the inside wall of the coupler head, from which seat it is dislodged on the closing movement of the knuckle in the act of coupling.

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Especial attention is called to the large area (practically 5 square inches) of the locking surface on the locking block and the knuckle in this coupler, and to the fact that no portion of the locking block extends beyond the bottom wall of the coupler.

This coupler has the desirable feature of easy accessibility of parts, thus facilitating repairs.

Manufactured by

The McCONWAY & TORLEY CO.

PITTSBURGH, PA.

MALLEABLE IRON AND STEEL CASTINGS